Effects of manipulations of local climate on processes and organisms in high arctic terrestrial ecosystems

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Front cover: From 28 - 30 July Arina Arctica from Royal Arctic Line anchored outside Zackenberg. During that period c. 220 helicopter slings were carried out between Arina Arctica and Zackenberg Research Station mainly with building materials and fuel. Photo Henning Thing.
Back of cover: In 2006 a photo competition were held among previous guests at Zackenberg Research Station. The purpose of the competition was to provide pictures for decoration of the new accommodation building at Zackenberg. The winners of the competition were: 1. Mikkel Peter Tamstorf (small river), 2. Stefano Massetti (halo over Zackenberg Research Station), and 3. Charlotte Sigsgaard (Zackenberg during sunset).

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Executive summary

Charlotte Sigsgaard, Niels Martin Schmidt and Morten Rasch

2006 was a very busy year at Zackenberg Research Station. In total, the station was visited by 33 scientists from the opening on 26 May until the closing on 31 August. The number of research projects carried out on the station totalled fifteen.

2006 was also the year in which our dream about modernising the station finally was fulfilled. This was accomplished with the construction of a new accommodation building housing 18 people and a new power station with three generators, a workshop and a garage at Zackenberg and a new boat house with plenty of space for all the boats involved in the research activities in Young Sund and Tyrolerfjord. The terrestrial part of Zackenberg Basic was evaluated by an international evaluation panel in 2006. The evaluation (Callaghan *et al.* 2006) was generally very positive. The main conclusion was that 'Zackenberg Research Station has been an outstanding success in the 10 years since its inception'. Besides this, the evaluation panel listed eight recommendations to improve the work at Zackenberg even further.

The ownership of Zackenberg Research Station was in 2006 transferred from The Ministry of Science, Technology and Innovation to The Greenland Home Rule. Concurrently with the transfer of the ownership, a covenant was signed which oblige Danish Polar Center to keep the station open and run it on the current conditions in the next ten years.

The field season in 2006 was characterized by a large accumulation of snow at the end of winter and relatively low temperatures in June and the first part of July resulting in a late snow melt. At the meteorological station the first positive diurnal air temperatures were measured 26 April and mean monthly temperatures in April and May were among the highest measured so far. With a mean monthly temperature of 1.0°C, June was the coldest recorded except from 1998 and air temperatures did not exceed 10°C until the middle of July. The last part of July was warm and included the highest temperature measured in Zackenberg since the meteorological station was established in 1995. The record high temperature of 22.8 °C was measured 21 July at midday and the mean monthly temperature in July (6.6°C) ended up being above average. Also August was warmer than average with a mean monthly temperature of 5.5°C.

The winter 2005/2006 was snow rich and by the end of winter an extensive snow cover was registered with one meter of snow at the meteorological station in the valley. On 10 June, the snow cover was much more extensive than previous years in all sub-zones in Zackenbergdalen and at the meteorological station snow lasted until 3 July.

Throughout the summer the total precipitation (rain) was only 15 mm which mainly fell in early and late July whereas June and August were relatively dry. Since 1998, it is the summer with the lowest registered precipitation.

Zackenbergelven broke up 12 June which is late compared to previous observations where break up have occurred between 30 May and 10 June. Water discharge peaked in the end of July in connection with the very warm period where the diurnal temperatures reached 16°C. By the end of August the river almost dried out but then 29 August, a large flood passed through Store Sødal and increased the discharge dramatically. In half a day, the water level increased from 25 cm to 188 cm at the hydrometric station. The water level peaked at midnight and in the morning 30 August the water level had dropped to 97 cm. No more observations were possible as the last people at the station left the same morning. What caused this surprisingly late flood was most likely drainage of a reservoir in the glaciated part of the drainage basin. Total runoff from the Zackenberg drainage basin in 2006 has been estimated to 169 mio. m^3. However, this amount is only preliminary as water was still running when the field season ended on 30 August.

During the flood, the suspended sediment concentration peaked at 5,566 mg/l and in total the transport of suspended sediment from the terrestrial to the marine ecosystem (Young Sund/Tyroler fiord) has been estimated to c. 27,000 tons.

The fiord ice between Zackenbergdalen and Clavering broke up 14 July, but not until 23 July there was open water all the way to the sea. After four years with an early break up of the fiord ice the situation in 2006 was more similar to what was experienced in 1997-2001 (where the fiord was open to the sea around 22 July).

In the two grid sites ZEROCALM-1 and ZEROCALM-2 where snow melt and active layer is measured throughout the field season, the onset of soil thaw was late due to the late snow melt. Still, the average thaw depth in the end of August reached a maximum of 76 cm in ZEROCALM-1 and 67 cm in ZEROCALM-2 which is respectively 15 and 24 cm deeper than in 1999, – a year that is comparable to 2006 in the timing of snow melt but had lower temperatures, especially in August.

From 27 May to 24 August CO_2 exchange between the well drained heath and the atmosphere was measured. Due to the late snow melt, the initiation of the growing season was the latest experienced since these measurements were started in 2000. The growing season lasted from 10 July to 24 August and in this period a total accumulation of 26.1 gC/m^2 was registered.

As an improvement of the gasflux monitoring a new setup was installed in the fen area (Tørvekæret) in order to implement methane flux monitoring in the GeoBasis programme. The setup consists of six automatic chambers where changes in carbon dioxide (CO_2) and methane (CH_4) concentrations are measured. Supplementary measurements of water level, thaw depth and micro meteorological parameters like soil temperature and solar insolation are recorded as well at this site. In 2006, the methane monitoring was operated from 3 July to 26 August and in this period 1.63 gC/m^2 was emitted.

The extensive snow cover and snow accumulation this season was also reflected in the phenology and numbers of most species in the BioBasis monitoring. The late snowmelt resulted in the latest or later than usual flowering recorded during the 11 years of monitoring for 24 of 28 plant plots, while flowering in the remaining 4 plots had flowering dates close to average. Two plots had earlier than usual flowering. The short growing season also resulted in late dates of 50% open seed capsules for the three species monitored. Also, more than 70% of all plots produced fewer flowers than the 1996-2005 average. Berry production on the other hand was generally high. The greening of the vegetation plots peaked with a single peak in mid or late July, which was relatively late compared to previous years, and with generally low NDVI values. Landscape NDVI inferred from a satellite image showed that, despite the late melting of the snow, NDVI in all sections was around the average of the previous years. Unlike last year, this year no catkins were found infested with fungi in any *Salix arctica* plot.

More than 31,700 arthropods were caught in window and pitfall traps, which is in the lower end of the numbers caught during the previous years. The exact number is, however, currently not known as a few but numerous groups (springtails, mites and ticks) have not yet been fully sorted. In the window traps, Chironomids constituted the bulk of specimens caught, and this group had a very distinct peak one week later than average for the years 1996-2005. In the pitfall traps, Chironimidae and Sciaridae were caught in high numbers, whereas groups such as Syrphidae, Muscidae and Aphids were caught in low numbers only, when compared to previous years. For the first time since 2003, sawfly larvae were feeding on *Salix* catkins in a study plot. Also, the percentage of *Dryas* flowers eaten by *Sympistis zetterstedtii* larvae was higher than usual, while *Gynaephora groenlandica* caterpillars were encountered in near-average numbers.

Bird breeding numbers were estimated later than usual due to the large amounts of snow. Sanderlings were recorded in record high numbers, even a little above the previous peak year 2003, and also dunlins and ruddy turnstones appeared in numbers above average. Common ringed plover and red knot were recorded in numbers around the average of previous years. Also the number of long-tailed skua territories was around average this season. After the last two seasons high numbers of snow bunting territories, numbers this season were lower again, although still the 3rd highest number recorded.

Wader nest initiation in 2006 was generally very late, and medians of the first egg dates were after 25 June in four of the five species monitored. Nest success, however, was fairly good for dunlin and very good for common ringed plover, whereas for sanderling and turnstone nest success was very low. The all-wader-predation rate was *c*. 63%, which is above average. The Arctic fox is the likely predator of most nests, as no nests were found with clear signs of avian predators, whereas fox encounters in the bird census area were high. For waders, mean clutch size was 3.4 which is lower than average. Also, the number of juvenile waders in the deltas at low tide was extremely low compared to previous seasons.

As for the waders, the long-tailed skua breeding initiation was late, and only two nests found within the bird census area. The number of pairs was similar to previous years, and most pairs thus seemed to be non-breeding.

The number of barnacle goose broods was among the lowest recorded so far, and the mean brood size was only 1.1 young per brood.

A total of 265 lemming winter nests were recorded within the lemming census area, which, compared to last year, represents a small increase. As last year, no lemming winter nests were depredated by stoats, and no stoats were observed during the field season either.

The pattern of musk ox occurrence in the valley and adjacent slopes generally fitted the pattern observed in the previous years well, i.e. low numbers during late May and June, and increasing numbers throughout July and August. The number of musk oxen per observation within the musk ox census area was in the high end of the numbers observed in the previous years. The sex and age composition of musk oxen, however, differed somewhat from previous years as generally fewer calves and older individuals were observed.

A minimum number of 17 arctic fox pups were registered at three den complexes, which is the second-highest number recorded so far. Also, the number of fox records in the field was higher than previously recorded.

An average of *c.*13 arctic hares was observed per census, with a maximum of 24 and a minimum of 5. This is a little higher than the previous record high in 2005, and much higher than the mean of all previous years.

An average of 14 seals were observed, which is similar to the 2005 number, but markedly lower compared to the average of the years 1997 through 2005.

The two lakes in the limnological monitoring programme had relatively late dates of ice-melt, but water temperatures were in the upper end of the range recorded since 1997. The average values for conductivity, total nitrogen and total phosphorus remained within the normal year-to-year fluctuations, whereas chlorophyll a concentrations were very low compared to previous years. In both lakes, the phytoplankton communities were dominated by chrysophytes. With respect to the zooplankton community in Sommerfuglesø, the cladoceran *Daphnia pulex* occured frequently, while in Langemandssø *D. pulex* was absent. This reflects the occurrence of arctic char in Langemandssø.

1 Introduction

Morten Rasch

2006 was a very busy year at Zackenberg Research Station. In total, the station was visited by 33 scientists from the opening on 26 May until the closing on 31 August. The number of research projects carried out on the station totalled fifteen. In August, eleven construction workers from the company Venslev Hytter raised a c. 175 m^2 accommodation building and a c. 75 m^2 combined power station, garage and workshop at Zackenberg and a c. 150 m^2 boathouse in Daneborg. In the middle of July the station was visited by a group of eight travellers led by a private investor, Frederik Paulsen, who have earlier supported Danish polar research. In early August the station was visited (only for a few hours) by a delegation from the Greenland Home Rule and in late August the station was visited by two persons from Aage V. Jensen Charity Foundation who have among other things funded the building of the three new houses at Zackenberg/Daneborg. To service all these people Danish Polar Center had employed at different times during the field season a total of seven logisticians.

Fig. 1.2. On 25 August in the morning new snow covered the entire Zackenberg valley. This did however not affect the construction workers from Venslev Hytter. Photo Morten Rasch.

Fig. 1.3. The boat house in Daneborg is situated just at the shore-line. The windows in the left side of the picture is leading to a combined laboratory and office facility with electrical heating. Photo Morten Rasch.

Extension and restoration of the facilities

2006 was the year in which our dream about modernising the station finally was fulfilled. This was accomplished with the construction of a new accommodation building housing 18 people (Fig. 1.1) and a new power station with three generators, a workshop and a garage (Fig. 1.2) at Zackenberg and a new boat house (Fig.1.3) with plenty of space for all the boats involved in the research activities in Young Sund and Tyrolerfjord. At Zackenberg, the construction work started immediately after the completion of a helicopter sling operation between 30 July and 3 August where 202 sling loads of building material were transported from the cargo ship Arina Arctica to the building site at Zackenberg (Fig. 1.4). The houses were erected by eight construction workers from the Danish contractor Venslev Hytter supported by staff from Danish Polar Center. Besides that the scientists at Zackenberg made invaluable help during the excavations for foundations. In Daneborg, the

Fig. 1.1. The new accommodation building was finalized in late August 2006 by construction workers from the company Venslev Hytter. The building holds accommodation facilities for 18 scientists, including a living room with a small kitchen. Photo Henrik Munch Spanggaard.

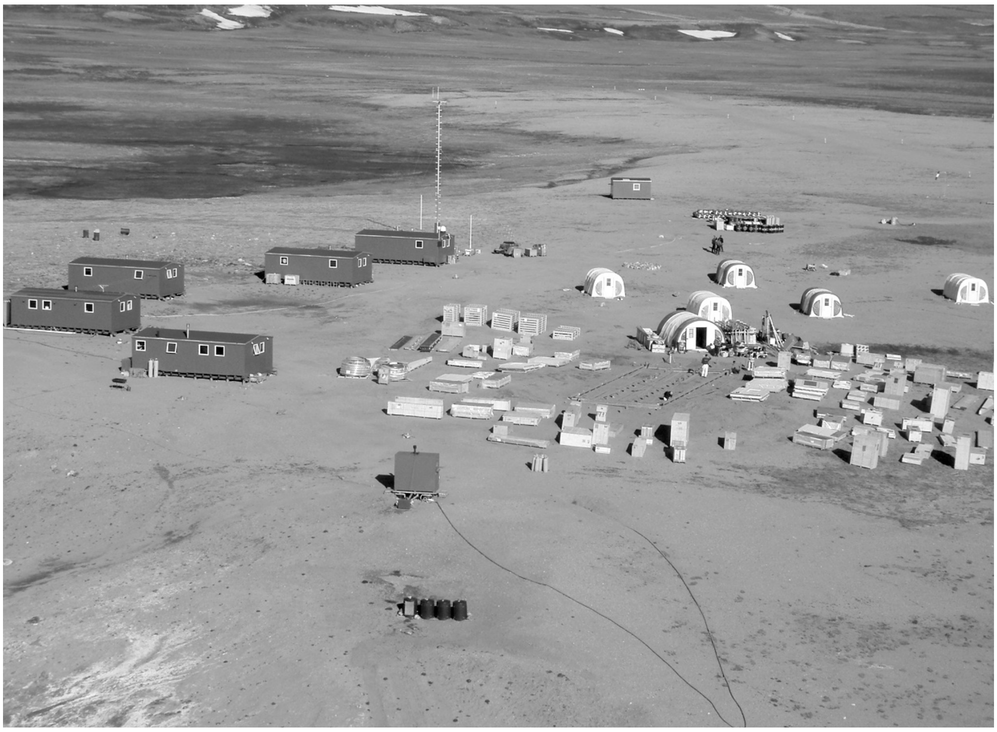


Fig. 1.4. Zackenberg Research Station immediately after the helicopter sling operation in early August. Photo Bent Olsen.

boat house was erected by five construction workers from Venslev Hytter. On 31 August, the houses were officially delivered by Venslev Hytter to Zackenberg Research Station.

This very important and necessary modernisation of Zackenberg Research Station would not have been possible without very generous support from Aage V. Jensen Charity Foundation. We are very grateful to Aage V. Jensens Charity Foundation because they in this way have helped the Danish-Greenlandic research and monitoring activities in the area.

Evaluation of Zackenberg Basic

The terrestrial part of Zackenberg Basic was evaluated by an international evaluation panel in 2006. The reason for not including the marine component of the programme, MarineBasis, in the evaluation was simply due to the shorter history of this programme. The three terrestrial programmes started in 1995 and as such these programmes have passed their ten years anniversary.

The evaluation panel was led by Professor Terry Callaghan. Besides being professor at Sheffield University, Dr. Callaghan is also Director of Abisko Scientific Research Station in northern Sweden. Terry Callaghan was accompanied in the evaluation panel by Dr. Craig Tweedie from University of Texas at El Paso and Dr. Bert Rudels from Finnish Institute of Marine Research. The evaluation was requested by The Danish Environmental Protection Agency who also funded the evaluation process.

The evaluation (Callaghan *et al.* 2006) was generally very positive. The main conclusion was that 'Zackenberg Research Station has been an outstanding success in the 10 years since its inception'. Besides this, the evaluation panel listed eight recommendations to improve the work at Zackenberg even further. These were:

1. Institutional and management arrangements shall be stabilised, clarified and simplified
2. Support to data management system shall be increased
3. Integration between monitoring subprogrammes shall be improved
4. The monitoring programmes shall be reviewed and if necessary modified
5. More base line shall be made available
6. The impact of the research shall be increased
7. Staff shall be more involved in international work
8. The stations infrastructure, facilities and logistics shall be improved.

The evaluation report in its full length is available on www.zackenberg.dk.

Transfer of ownership to the Greenland Home Rule

The ownership of Zackenberg Research Station was in 2006 transferred from The Ministry of Science, Technology and Innovation to The Greenland Home Rule. Concurrently with the transfer of the ownership, a covenant was signed which oblige Danish Polar Center to keep the station open and run it on the current conditions in the next ten years. The transfer of the ownership was a prerequisite for the donation made by Aage V. Jensen Charity Foundation for modernisation and extension of the station's facilities. It is the plan to celebrate the transfer of the ownership in connection with the celebration of the stations ten years anniversary, which is planned to be held at Zackenberg in the summer of 2007 and with participation of relevant ministers from Denmark and Greenland.

International cooperation

Zackenberg Research Station is still involved in the networks ENVINET (European Network of Arctic-Alpine Environmental Research), SCANNET (Scandinavian / North European Network of Terrestrial Field Bases) and CEON (Circum-Arctic Environmental Observatories Network). The station is further involved in or support a large number of international organizations, programs, processes and networks including AMAP (Arctic Minitoring and Assessment Programme), CAFF (Conservation of Arctic Flora and Fauna), ACIA (Arctic Climate Impact Assessment), ITEX (International Tundra Experiment), GRDC (Global Runoff Data Center), GTOS (Global Terrestrial Observing System), CALM (Circumpolar Active Layer Monitoring Programme), ACD (Arctic Coastal Dynamics), ABBCS (Arctic Birds Breeding Conditions Survey) and PASNR (Pan-Arctic Shorebird Researchers Network). In 2006, attempts were made to attach Zackenberg Basic more closely to the coordinated monitoring/research programme GLORIA (Global Observation Research Initiative in Alpine Environments). Besides that, Zackenberg staff are deeply involved in different part of the planning in relation to The International Polar Year (IPY), and Zackenberg scientists participates in several of the IPY research clusters. Zackenberg also contributed to the ongoing more strategic international initiatives relating to establishment of an infrastructure for future climate change studies. As examples of this can be mentioned that Zackenberg scientists participated in several of the working groups at the ICARP-II conference in Copenhagen 2005 (working group reports finalised in 2006), and that Zackenberg contributed to the report 'Towards an Integrated Arctic Observing Network' (Committee on Designing an Arctic Observing Network, National Research Council 2006) that was published by The National Academies (USA) in 2006.

Nuuk Basic, a West Greenland equivalent of Zackenberg Basic

The Danish Environmental Protection Agency asked in 2005 the institutions involved in Zackenberg Basic if they could manage to extend the monitoring at Zackenberg with a similar but low arctic monitoring programme on the Greenland west coast at Nuuk, The Capital of Greenland. The new programme, named Nuuk Basic, will be carried out by the same monitoring programmes (ClimateBasic, GeoBasic, BioBasic and MarineBasic) that is already involved in the monitoring at Zackenberg. The secretariat of the programme will be situated at Danish Polar Center in close connection with the Zackenberg Secretariat. In 2006, the final more formal agreements concerning financing and structuring of the programme were concluded, and the programme is now ready to launch on practice by establishment of field sites in Kobbefjord in the summer of 2007.

'The dynamics of a High Arctic Ecosystem in Relation to Climate variability and Change'

The writing process that shall lead to reporting of the first ten years of monitoring at Zackenberg was continued in 2006. The work started at a workshop on Menstrup Kro in 2005 with participation of c. 50 co-authors, and it is the plan that the book shall be published in late 2007. 2006 has mainly been used for the different groups of scientists responsible for the planned 24 chapters to write. Elsevier has accepted to publish the manuscript in one of their series of books called 'Advances in Ecological Research'.

Plans for the 2007 field season

Zackenberg Research Station was officially opened in August 1997. As a result the station has ten years anniversary next year. The anniversary will be celebrated in August 2007 where we expect that several Danish and Greenlandic ministers and other honourable guests will visit the station.

In 2007, The International Polar Year (IPY), which will run from 2007 to 2009 starts on 1 March. It has for long time been a strong wish among the scientists working at Zackenberg to keep the station open for one winter to accomplish winter measurements of the same parameters that has for many years been measured during the summer. Such winter measurements of high arctic ecosystem function/dynamics during winter are very rare. In The Zackenberg Ecological Research Operations Working Group we have therefore decided that keeping the different field measurements running at Zackenberg throughout IPY would be an adequately ambitious goal as a Zackenberg contribution to IPY. During the late part of the field season, Zackenberg Research Station was visited by representatives from Aage V. Jensen Charity Foundation. They recognised certain tasks that could improve the station facilities even further. As a result, the foundation offered, among other things, in late autumn 2006 to finance an extension and modernisation of the mess building at Zackenberg. We are therefore planning again next year to have construction workers at the station in most of August to improve our mess with a 50 m^2 dinning room, a modernised kitchen (25 m^2) and a new food storage room (25 m^2).
Besides all theses activities related specifically to Zackenberg, we also expect bustle due to the establishment of Nuuk Basic in West Greenland which involves many of the scientists also involved in the work at Zackenberg.

Finally we expect more than average research activities at the station in 2007-8 due to the expectation that much more funding will, on an international scale, be granted to polar research during The International Polar Year.

Further information

Information about Zackenberg Research Station and the study area at Zackenberg are published in previous annual reports (Meltofte and Thing 1996, 1997; Meltofte and Rasch 1998; Rasch 1999, Caning and Rasch 2000, 2001, 2003; Rasch and Caning 2003, 2004, 2005; Klitgaard *et al.* 2006) and much information is also available on the Zackenberg homepage (www.zackenberg.dk). The ZERO Site Manual, available on www.zackenberg.dk, collects information relevant to scientists planning to use Zackenberg Research Station for research projects. The address of the secretariat is: The Zackenberg Research Station Secretariat, Danish Polar Center, Strandgade 102, DK-1401 Copenhagen K, Denmark, phone (+45) 32880100, fax (+45) 32880101, e-mail mr@fi.dk.

2 ZACKENBERG BASIC
The ClimateBasis and GeoBasis programmes

Charlotte Sigsgaard, Kisser Thorsøe, Annette W. Fugl, Mikhail Mastepanov, Thomas Friborg, Mikkel Tamstorf, Birger Ulf Hansen, Lena Ström and Torben Røjle Christensen

The aim of GeoBasis and ClimateBasis is to provide long term data of climatic, hydrological and physical landscape variables describing the environment at Zackenberg. GeoBasis is operated by the National Environmental Research Institute, Department for Arctic Environment in co-operation with Department of Geography and Geology, University of Copenhagen. GeoBasis is funded by the Danish Environmental Protection Agency as part of the environmental support programme Dancea – Danish Cooperation for Environment in the Arctic. ClimateBasis is funded by the Greenland Home Rule and operated by ASIAQ, Greenland Survey, who operates and maintains the climate station and the hydrometric station.

The authors are solely responsible for all results and conclusions presented in the report, which does not necessarily reflect the position of the Danish Environmental Protection Agency.

The monitoring includes climatic measurements, seasonal and spatial variations in snow cover and local microclimate in the Zackenberg area, the water balance of Zackenbergelven drainage basin, the sediment, solute and organic matter yield of Zackenbergelven, the carbon dioxide (CO_2) fluxes from a well drained heath site, the seasonal development of the active layer, temperature conditions and soil water chemistry of the active layer, and the dynamics of selected coastal and periglacial landscape elements. As an improvement of the gasflux monitoring a methane programme has been implemented in GeoBasis in 2006.

More details about the GeoBasis programme, sampling procedures, instrumentation, locations and installations are given

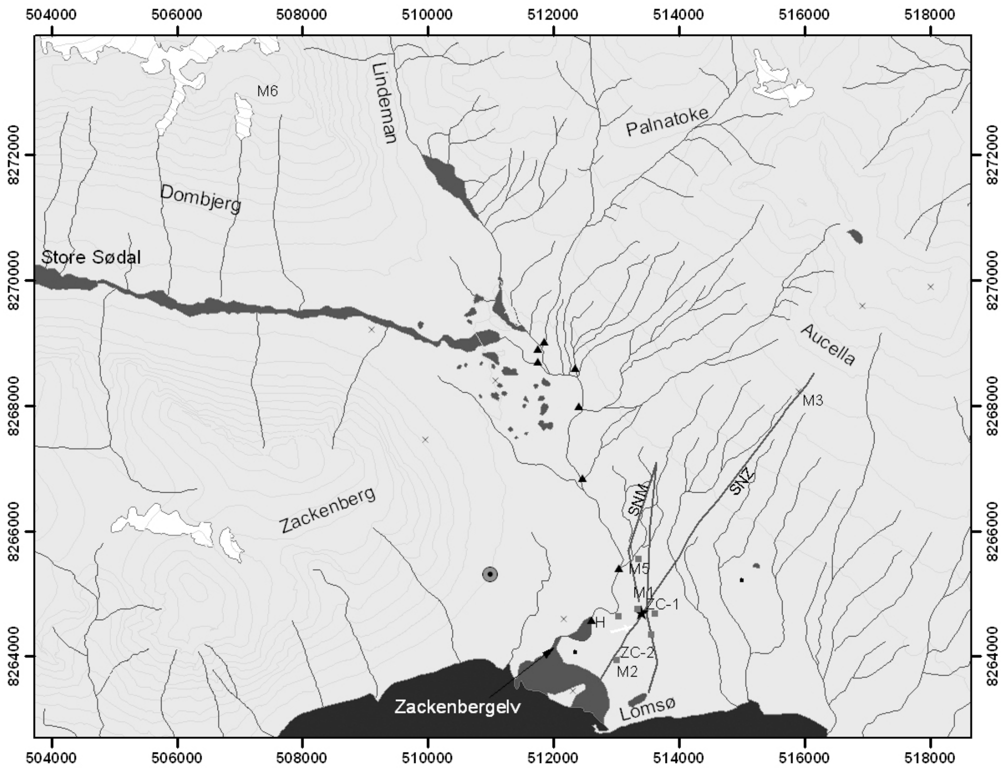


Fig. 2.1. Location of GeoBasis and ClimateBasis stations and plots. The meteorological station is marked with an asterix. H= Hydrometric station. M1= Micrometeorological station. M2 and M3= Snow- and micrometeorological stations. M5= Methane site. M6= Dome meteorological station. Triangles = Water sampling sites from tributaries to Zackenbergelven. Circle = Nansenblokken. Squares= Soil water sites. Crosses = TinyTag temperature sites. SNM and SNZ=Snow depth transects. ZC-1 and ZC-2 = Active layer monitoring sites.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Yearly mean values											
Air temperature, 2 m above terrain (°C)	-9.0	-10.1	-9.7	-9.5	-10.0	-9.7	-8.6	-9.2	-8.5	-7.7	-8.1
Air temperature, 7.5 m above terrain (°C)	-8.4	-9.3	-9.1	-8.9	-9.4	-9.2	-	-8.7	-7.9	-6.9	-7.6
Relative air humidity 2 m above terrain (%)	67	68	73	70	70	71	72	71	72	71	72
Air Pressure (hPa)	1009	1007	1010	1006	1008	1009	1009	1008	1007	1008	1007
Incoming shortwave radiation (W/m^2)	113	104	101	100	107	112	105	104	99	101	107
Outgoing shortwave radiation (W/m^2)	52	56	55	56	52	56	54	49	42	43	54
Net Radiation (W/m^2)	16	9	6	4	14	13	-	8	-	-	11
Wind Velocity, 2 m above terrain (m/s)	2.7	3.0	2.6	3.0	2.9	3.0	2.8	2.6	3.0	2.9	2.7*
Wind Velocity, 7.5 m above terrain (m/s)	3.1	3.4	3.2	3.7	3.3	3.4	3.3	3.1	3.6	3.5	3.4
Precipitation (mm w.eq.), total	223	307	255	161	176	236	174	263	253	254	-
Yearly maximum values											
Air temperature, 2 m above terrain (°C)	16.6	21.3	13.8	15.2	19.1	12.6	14.9	16.7	19.1	21.8	22.8
Air temperature, 7.5 m above terrain (°C)	15.9	21.1	13.6	14.6	18.8	12.4	-	16.7	18.5	21.6	22.1
Relative air humidity 2 m above terrain (%)	99	99	99	99	100	100	100	100	100	99	99
Air Pressure (hPa)	1042	1035	1036	1035	1036	1043	1038	1038	1033	1038	1038
Incoming shortwave radiation (W/m^2)	857	864	833	889	810	818	920	802	795	778	833
Outgoing shortwave radiation (W/m^2)	683	566	632	603	581	620	741	549	698	629	684
Net Radiation (W/m^2)	609	634	556	471	627	602	-	580	-	-	538
Wind Velocity, 2 m above terrain (m/s)	20.2	22.6	25.6	19.3	25.6	20.6	21.6	20.6	22.2	19.9	20.8*
Wind Velocity, 7.5 m above terrain (m/s)	23.1	26.2	29.5	22.0	23.5	25.0	25.4	23.3	25.6	22.0	22.8
Yearly minimum values											
Air temperature, 2 m above terrain (°C)	-33.7	-36.2	-38.9	-36.3	-36.7	-35.1	-37.7	-34.0	-34.0	-29.4	-38.7
Air temperature, 7.5 m above terrain (°C)	-31.9	-34.6	-37.1	-34.4	-34.1	-33.0	-	-32	-32.1	-27.9	-37.2
Relative air humidity 2 m above terrain (%)	20	18	31	30	19	22	23	21	17	22	21
Air Pressure (hPa)	956	953	975	961	969	972	955	967	955	967	968
Incoming shortwave radiation (W/m^2)	0	0	0	0	0	0	0	0	0	0	0
Outgoing shortwave radiation (W/m^2)	0	0	0	0	0	0	0	0	0	0	0
Net Radiation (W/m^2)	-86	-165	-199	-100	-129	-124	-	-98	-	-	-99
Wind Velocity, 2 m above terrain (m/s)	0	0	0	0	0	0	0	0	0	0	0
Wind Velocity, 7.5 m above terrain (m/s)	0	0	0	0	0	0	0	0	0	0	0

*Table 2.1. Yearly mean, maximum and minimum values of climate parameters for 1996 to 2006. Data for 2006 are preliminary. *) only valid data until 2 September. Some of the figures differ from earlier publications due to re-evaluation of data. Please note, that the total annual precipitation differs from the total precipitation in the hydrological year (1 October to 30 September) in Table 2.12)*

in the GeoBasis Manual which is available from the Zackenberg homepage: www.zackenberg.dk. Through this internet homepage all validated data from the Zackenberg Basic monitoring are accessible. If some data collected by ClimateBasis and GeoBasis are not available through the database, they can be ordered from ASIAQ (kit@asiaq.gl) and Department of Geography and Geology (cs@geogr.ku.dk), respectively.

In the following section ClimateBasis and GeoBasis monitoring data are summarised and the season 2006 presented. Location of most GeoBasis and ClimateBasis stations and plots, referred to in the text, are given in Fig. 2.1.

GeoBasis was able to start manual measurements in Zackenberg 26 May and the field season lasted to 29 August 2006.

2.1 Meteorological data

The meteorological station at Zackenberg was constructed in summer 1995. Technical specifications of the station are described in Meltofte and Thing (1996). Once a year the sensors are inspected and calibrated by ASIAQ, Greenland Survey. In the summer 2005, a satellite modem was mounted on the eastern mast and the transferred data made available on the Zackenberg homepage: www.zackenberg.dk/weather. For the period September to December 2006 where data is only available from the east mast, the quality control of data is provisional until data from the west mast has been retrieved in the summer 2007. Some parameters are only measured at the west mast (e.g. precipitation) and these will be presented in the next annual report. Some of the data from earlier years presented in Table 2.1 and 2.2

Fig. 2.2. The new foundation of the Belfort precipitation gauge that elevates the measuring device above the ground and thereby hopefully reduces problems with freezing water around the equipment.

Fig. 2.3. The new meteorological station (M6) on Domebjerget is located 1282 m a.s.l. Snow depth is measured from a separate mast whereas all other parameters are measured from the main mast where also the solar panel and two enclosures for datalogger and batteries are mounted.

differs from earlier publications due to re-evaluation of data.

During the inspection in August 2006, several new installations took place. The soil temperature set up at the climate station was replaced due to malfunction of several old sensors. The new soil profile was made c.10 meters from the old profile and temperature sensors were installed at similar depths as in the old profile (see section 2.2).

The Belfort precipitation gauge was supplied with a new foundation and the gauge was lifted c. 40 cm above the ground. Elevation of the gauge was made in order to reduce problems with freezing melt water at the measuring device (Fig. 2.2).

New meteorological station

In August 2006, a new meteorological station was installed on Domebjerget. The station (M6 UTM: 8273009 mN, 507453 mE) was placed on a gently, south facing plateau east of the very top of Domebjerget at an elevation of 1282 m a.s.l (Fig. 2.3) The surface is characterized by rocks and boulders and hardly any vegetation is present. Data from the new station will contribute to the understanding of temperature gradients and inversion events as well as the altitudinal distribution of snow cover. Besides air temperature, the new station monitors relative humidity, wind speed, wind direction, air pressure, snow depth and ground level temperature. Snow depth is measured every third hour from a separate mast. Air temperature, relative humidity and wind are measured two meter above ground on an hourly basis (10 min for wind parameters). Data from the sensors are logged by a CR10X Campbell Scientific datalogger. The station is powered by two 12V, 100 Ah batteries, which are charged by a MSX64 solar panel.

Meteorological data from 2005

In 2005, the mean air temperature measured 2 m above terrain was –7.7°C. A maximum temperature of 21.8°C was measured 21 July and a minimum temperature

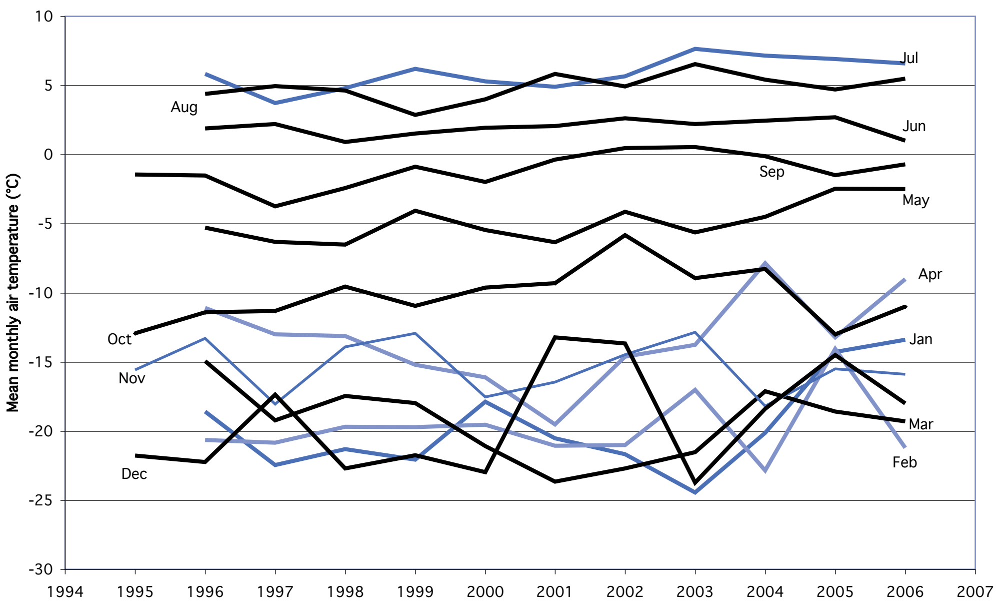


Fig. 2.4. Monthly mean temperatures in the period from September 1995 to August 2006.

Year	Month	Shortwave Rad. W/m² mean in	Shortwave Rad. W/m² mean out	Net Rad. W/m² mean	PAR μmol/m²/s mean	Air temperature °C mean 2 m	Air temperature °C minimum 2 m	Air temperature °C max 2 m	Precipitation mm total	Wind velocity m/s mean 7.5 m	Wind velocity m/s max¹) 7.5 m	Vind direction dominant 7.5 m
	Jun	222	111	85	-	2.2	-4.4	12.0	23	2.4	14.1	ESE
1997	Jul	225	23	130	-	3.7	-1.0	15.3	28	2.7	13.8	SE
	Aug	159	20	74	-	5.0	-3.0	21.3	16	2.8	13.3	SE
	Jun	270	172	51	-	0.9	-3.0	9.6	5	1.6	8.1	SE
1998	Jul	204	20	125	-	4.7	-2.6	13.8	33	2.3	12.1	SE
	Aug	114	12	64	-	4.6	-1.8	11.5	55	2.4	12.2	ESE
	Jun	294	206	33	-	1.5	-4.5	10.4	2	2.3	15.0	-
1999	Jul	212	32	123	-	6.2	-0.7	15.1	21	2.6	14.8	-
	Aug	143	16	73	-	2.9	-2.7	15.2	11	2.5	14.9	SE
	Jun	294	103	126	-	1.9	-6.2	11.7	10	2.1	15.1	SE
2000	Jul	228	27	141	-	5.3	-1.2	19.1	13	2.9	15.9	SE
	Aug	153	19	82	-	4.0	-3.5	11.6	0	2.3	13.4	SE
	Jun	293	168	67	-	2.1	-4.9	11.9	26	2.1	13.3	-
2001	Jul	231	27	146	-	4.9	-1.5	11.8	7	2.9	13.1	-
	Aug	180	20	84	-	5.8	-0.8	12.6	21	2.9	14.4	-
	Jun	344	151	113	-	2.6	-2.8	14.9	1	1.6	6.8	SE
2002	Jul	205	23	105	424	5.7	-0.9	13.8	11	2.6	9.9	SE
	Aug	129	16	51	272	4.9	-3.1	11.6	15	2.8	12.9	SE
	Jun	294	108	106	612	2.2	-4.8	14.7	7	1.6	5.4	SE
2003	Jul	210	26	96	431	7.7	1.8	16.7	6	2.8	14.2	SE
	Aug	151	20	56	313	6.6	-0.5	15.4	3	2.5	10.1	SE
	Jun	279	73	111	571	2.5	-3.4	19.1	3	2.3	13.6	SE
2004	Jul	225	30	95	464	7.2	-0.7	19.0	10	2.8	10.5	SE
	Aug	150	20	62	302	5.6	-1.4	17.2	4	2.4	12.6	SE
	Jun	261	53	-	519	2.7	-3.5	13.4	6	2.4	11.8	SE
2005	Jul	215	29	-	428	6.9	-0.6	21.8	28	2.9	13.3	SE
	Aug	153	21	51	321	4.6	-2.7	14.0	4	3.2	10.9	SE
	Jun	312	208	54	675	1.0	-4.4	9.5	5	1.7	6.9	SE
2006	Jul	256	28	131	550	6.6	-1.2	22.8	9	2.5	11.3	SE
	Aug	158	21	61	336	5.5	-4.5	16.3	1	2.6	12.0	SE

Table 2.2. Climate parameters for June, July and August, 1997 to 2006.
1) Wind velocity, max is the maximum of 10 minutes mean values. Some of the figures differ from earlier publications due to re-evaluation of data.

of –29.4°C was measured 22 January (Table 2.1). The high annual mean air temperature was mainly due to unusually high temperatures in January and February as well as in May and June (Fig 2.4). In contrast, October was colder than measured before.

Mean relative humidity was 71% and the lowest relative humidity of 22 % was measured 26 January during a period where a Föhn wind resulted in temperatures up to 10.7°C. The highest values and largest fluctuations of relative humidity were observed during summer. The mean air pressure was 1008 hPa. Highest air pressures were registered in March, April and May and the air pressure was more stable during summer than winter (Table 2.3 and Fig. 2.5).

Mean wind speed 2 m and 7.5 m above the ground was 2.9 m/s and 3.5 m/s, respectively. The highest 10 minutes mean value was 19.9 m/s at 2 m above ground and 22.0 m/s at 7.5 m above ground both measured during a storm 25 January 2005

The total amount of measured precipitation in 2005 was 254 mm. Precipitation in the summer period was 38 mm and occurred primarily in July whereas June and August were rather dry (Table 2.2).

Meteorological data from 2006

In 2006, the mean air temperature measured 2 m above terrain was -8.1°C. The period with frequent temperatures above 0°C started in late April and ended in late September. January had a mean monthly temperature of -13.4°C and was the warmest recorded so far (Table 2.3 and Fig 2.4). April and May were also characterized by high temperatures but the warm spring was followed by a cold start of the summer. June and the first part of July was cold and air temperatures above 10°C were not measured until 17 July. Then the temperature peaked and a maximum temperature of 22.8° were recorded 21

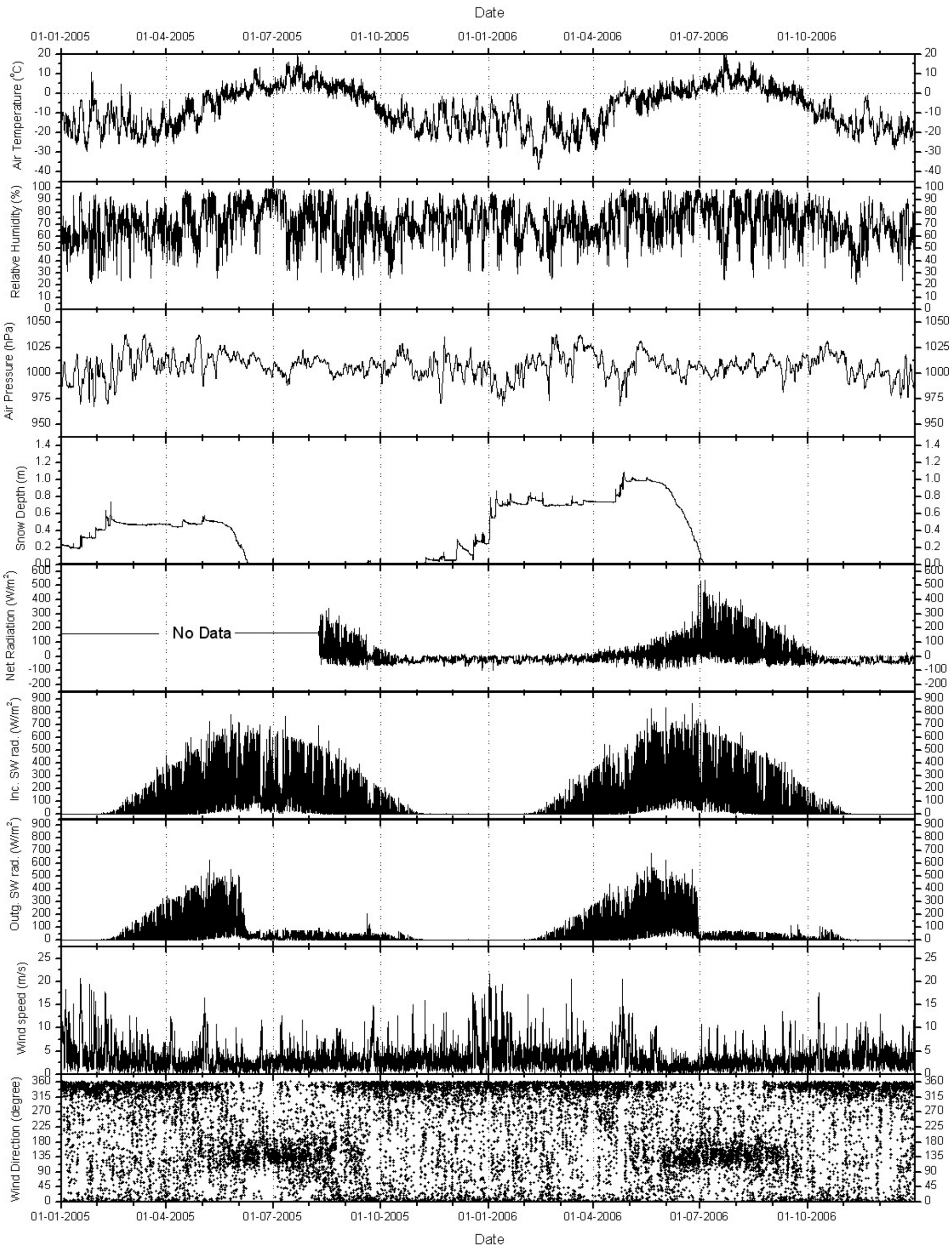


Fig. 2.5. Variation of selected climate parameters during 2005 and 2006. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation, outgoing short wave radiation, wind speed and wind direction. Wind speed and direction are measured 7.5 m above terrain; the remaining parameters are measured 2 m above terrain.

July. This is the highest air temperature recorded since the climate station was established in 1995. Due to some very warm days with diurnal mean temperatures up to 16°C in the last part of July, the monthly mean temperature (6.6°C) ended up being above average. August had a mean monthly temperature of 5.5°C and was also warmer than average for the last ten years. Positive degree days calculated on a monthly basis as the sum of daily mean air temperatures above 0°C are shown in Table 2.4. Only in 1998, the sum of degree days for June has been lower than in 2006.

Mean relative humidity was 72%, and mean air pressure was 1,007 hPa. Monthly mean net radiation was positive from May to September 2006 and negative in October to December and from January to April.

Unfortunately, the wind speed sensor in 2 m on the east mast was broken on 2 September and therefore the mean wind speed in 2 m will first be presented in the next annual report when data from the west mast has been collected. Mean wind speed 7.5 m above the ground was 3.4 m/s. The highest 10 minutes mean value of 22.8 m/s at 7.5 m above ground was measured 3 January. The yearly wind statistic for 2006 is in good agreement with the years 1997, 1998, 2000, 2002 and 2004. Wind statistics for the remaining years are not given due to significant periods

Year	Month	Air Temperature °C 2.0 m	Air Temperature °C 7.5 m	Rel. humidity %	Air Press. hPa	Net Rad. W/m²	Shortwave Rad. W/m² In	Shortwave Rad. W/m² Out	Wind Velocity m/s 2.0 m	Wind Velocity m/s 7.5 m	Dominant Wind Dir. 7.5 m
2005	Jan	-14.3	-12.9	62	996.0	-	0	0	5.0	6.0	NNW
2005	Feb	-14.1	-12.5	65	1004.6	-	7	6	3.3	4.1	NNW
2005	Mar	-18.6	-17.1	68	1014.3	-	62	53	2.4	2.8	NNW
2005	Apr	-13.2	-11.9	67	1013.5	-	164	136	2.3	2.7	NNW
2005	May	-2.5	-1.8	76	1014.8	-	256	197	2.5	3.1	N
2005	Jun	2.7	2.9	84	1010.2	-	261	53	2.0	2.4	SE
2005	Jul	6.9	7.1	75	1006.3	-	215	29	2.4	2.9	SE
2005	Aug	4.6	4.8	69	1006.7	51	153	21	2.6	3.2	SE
2005	Sept	-1.5	-1.3	68	1005.8	1	73	15	2.7	3.3	N
2005	Oct	-13.0	-12.3	67	1010.0	-31	17	6	2.6	3.4	N
2005	Nov	-15.5	-14.7	72	1003.8	-21	0	0	2.7	3.4	N
2005	Dec	-14.5	-13.5	73	1004.4	-18	0	0	3.6	4.3	N
2006	Jan	-13.4	-12.7	72	991.2	-18	0	0	4.4	5.3	N
2006	Feb	-21.2	-20.0	65	1013.3	-20	7	5	3.0	3.7	N
2006	Mar	-19.3	-18.4	68	1020.8	-16	56	45	3.0	3.7	N
2006	Apr	-9.0	-8.4	73	1001.5	-4	137	114	3.6	4.5	NNW
2006	May	-2.5	-2.4	76	1015.5	11	260	207	2.4	3.1	N
2006	Jun	1.0	0.7	82	1003.8	54	312	208	1.3	1.7	SE
2006	Jul	6.6	5.9	77	1004.5	131	256	28	2.1	2.5	SE
2006	Aug	5.5	5.3	75	1008.2	61	158	21	2.2	2.6	SE
2006	Sept	-0.7	-0.7	76	1007.4	6	75	13	0.0	3.0	NNW
2006	Oct	-11.0	-9.9	72	1017.2	-28	15	7	0.0	3.5	NNW
2006	Nov	-15.9	-14.8	60	1001.0	-30	0	0	0.0	3.8	NNW
2006	Dec	-18.0	-16.7	66	995.5	-26	0	0	0.0	3.5	NNW

Table 2.3. Monthly mean values of climate parameters 2005 and 2006. Data for 2006 are preliminary.

with missing data. In 2006, the winds were coming from N and NNW app. 40% of the time, mainly in the winter period, and from ESE to SSE app. 21% of the time, mainly in the summer period (Table 2.3 and 2.5).

The total precipitation during the summer of 2006 was 15 mm and occurred primarily in July whereas June and August as in 2004 and 2005 were rather dry (Table 2.2). Since 1998 it is the summer with the lowest registered precipitation.

2.2 Climate gradients, snow, ice and permafrost

Snow and micrometeorological stations

Monthly mean values of selected parameters from the snow- and micrometeorological stations M2 and M3 (section 2.2 in Rasch and Caning 2004) are reported in Table 2.6 and Fig.2.6. A new program was installed at M2 and M3 in August 2006 but an error occurred during the first download at M3 and therefore no data are available in the period from 11 August to

*Table 2.4. Positive degree days calculated on a monthly basis as the sum of daily mean air temperatures above 0°C. Calculations are based on air temperatures from the climate station (2 m above ground) *) Preliminary values.*

Degree days	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
January											1.5	
February												
March												
April									0.2	1.1		2.9
May		1.1	1.3	0.1	3.6	0.5	0.5	18.2	3.3	4.1	5.40	3.1
June		63.7	74.6	32.5	52.9	71.8	68.2	81.8	74.2	73.9	84.6	37.2
July		181.0	115.4	147.36	192.7	164.4	152.0	175.6	237.2	222.2	214.7	205.3
August		140.5	154.2	143.6	89.2	127.3	181.2	152.5	203.2	169.4	141.5	*158.6
September	11.7	15.3	4.5	11.3	19.7	5.7	31.1	41.2	42.5	41.4	17.7	
October			1.5				0.3	1.8				
November												
December												
Sum	**11.7**	**401.7**	**351.5**	**334.8**	**358.0**	**369.7**	**433.2**	**471.1**	**560.6**	**514.8**	**466.4**	***407.1**

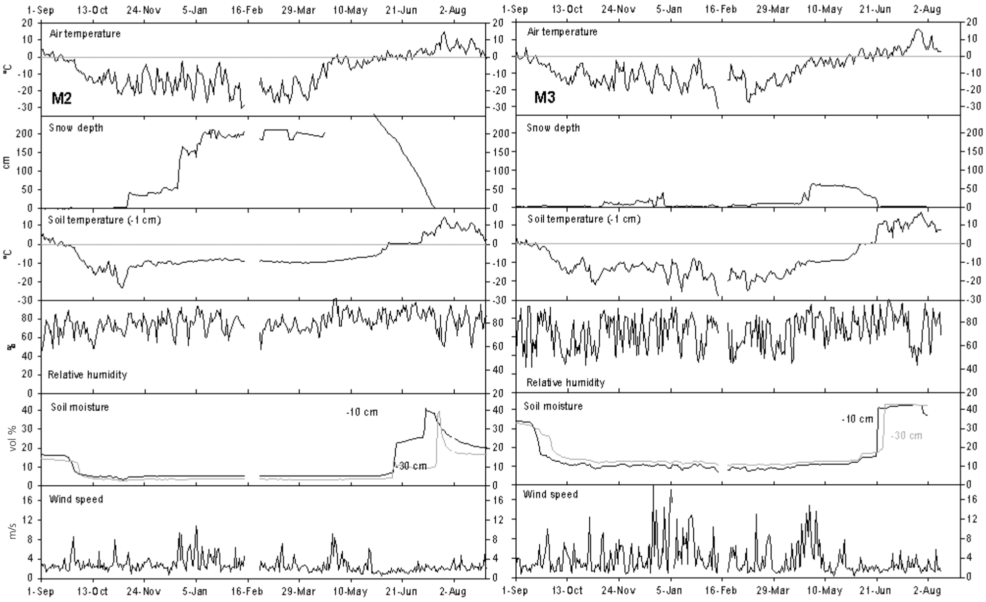


Fig. 2.6. Daily mean values of selected parameters from snow- and micrometeorological station M2 (17 m a.s.l.) and M3 (420 m a.s.l.) in the period September 2005 to August 2006. From above: Air temperature, snow depth, soil temperature 1 cm below surface, relative humidity, soil moisture 10 cm and 30 cm below surface and wind speed.

24 August 2006. Due to a lack of power from the solar panels in the winter there are a few drop outs of data from 11-17 February at M3 and from 11-21 February at M2. Therefore, it has not been possible to calculate monthly mean values for February.

Comparing the air temperature at M2 and M3 reveals, that the temperature is often higher at M3 (420 m a.s.l.) than at M2 (17 m a.s.l.). This temperature inversion is most pronounced during the winter months, whereas May and September is the month with lowest occurrence of temperature inversions (Table 2.7). The largest temperature inversion in 2006 was measured 18 March where a deviation of 17.5 °C was registered.

Snow depth

In 1997, automatic measurements of snow depth were started in Zackenbergdalen near the meteorological station; see Meltofte and Rasch (1998). Snow depth during the winter is summarised for all nine winters in Table 2.8 and the accumulation for all years is shown in Fig. 2.7. The winter 2005/2006 was snow rich and by the end of winter an extensive snow cover

Table 2.5. Mean wind statistics based on wind velocity and direction measured 7.5 m above terrain in 1997, 1998, 2000, 2002, 2003 and 2004. Furthermore wind statistics for the years 2005 and 2006. Calm is defined as wind speed lower than 0.5 m/s. Max speed is maximum of 10 minutes mean values. Mean of maxs is the mean of the yearly maximums. The frequency for each direction is given as percent of the time for which data exist. Missing data amount to less than 8% of data for the entire year and less than 20 days within the same month.

Year	Mean[1)]				2005			2006		
Direction	Frequency	Velocity, m/s			Frequency	Velocity, m/s		Frequency	Velocity, m/s	
	%	mean	mean of maxs	max	%	mean	max	%	mean	max
N	14.2	4.3	24.5	29.5	19.8	4.8	21.2	20.5	5.0	22.3
NNE	3.5	2.7	17.9	25.4	4.0	2.8	16.4	3.8	2.6	17.8
NE	2.5	2.5	15.3	19.4	2.7	2.4	11.0	2.4	2.2	12.1
ENE	2.8	2.4	13.7	17.4	3.1	2.9	11.9	2.5	2.2	11.3
E	4.1	2.1	9.2	10.5	3.5	2.3	10.7	3.5	2.1	8.5
ESE	7.1	2.2	9.2	10.3	5.7	2.4	8.5	6.4	2.3	9.4
SE	8.5	2.4	10.3	18.1	8.4	2.6	8.0	8.8	2.4	9.8
SSE	5.6	2.4	10.1	16.2	6.2	2.5	8.1	5.9	2.5	8.4
S	3.9	2.5	8.3	9.9	4.7	2.5	6.8	4.0	2.6	8.0
SSW	2.9	2.3	9.3	13.4	2.9	2.3	7.2	2.7	2.4	6.9
SW	2.5	2.2	8.7	12.2	2.6	2.2	7.0	2.7	2.1	8.2
WSW	2.8	2.4	10.6	15.9	3.1	2.4	6.7	3.3	2.3	7.8
W	2.9	2.6	18.6	23.5	3.0	2.6	18.1	2.8	2.2	6.5
WNW	3.3	2.7	17.0	19.3	3.2	2.8	18.1	3.0	2.3	11.7
NW	6.5	3.6	20.3	25.1	6.2	3.8	18.4	5.9	3.4	19.8
NNW	23.6	5.1	23.2	25.8	18.8	5.0	22.0	19.9	4.9	22.8
Calm	4.3				2.1			1.8		

[1)] Data from 1997, 1998, 2000, 2002, 2003, 2004

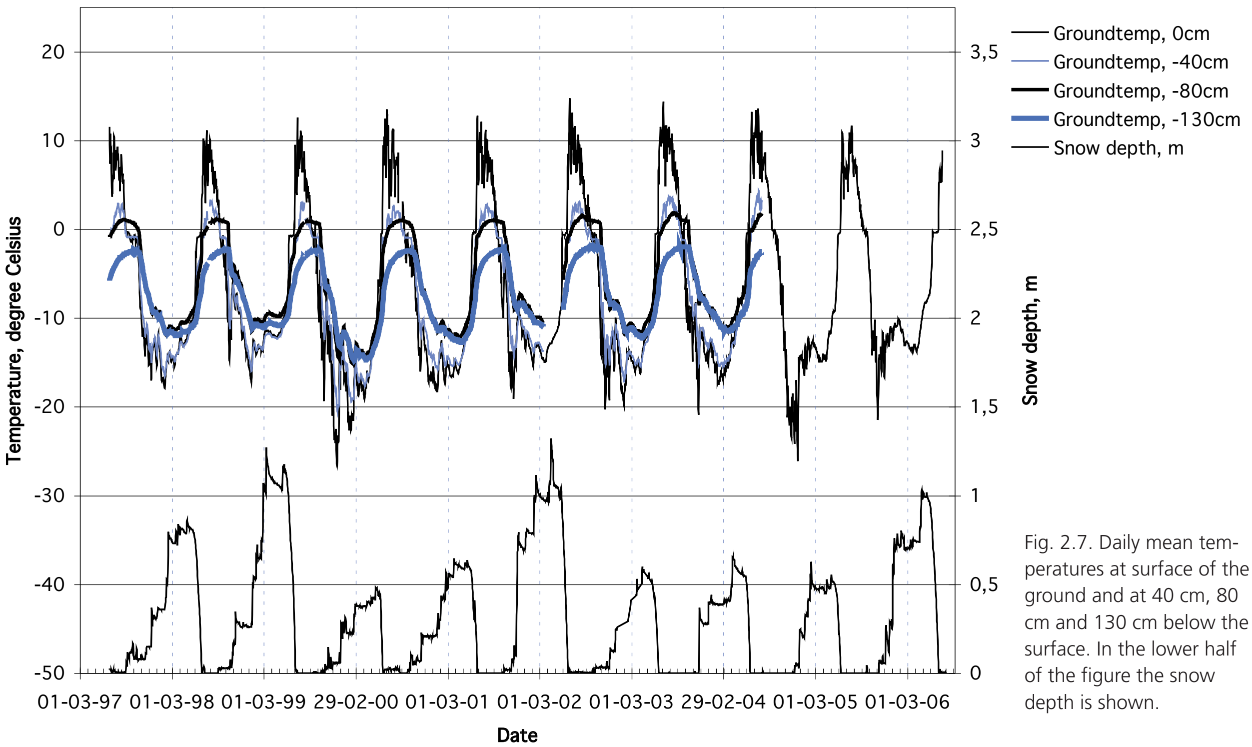


Fig. 2.7. Daily mean temperatures at surface of the ground and at 40 cm, 80 cm and 130 cm below the surface. In the lower half of the figure the snow depth is shown.

was registered with one meter of snow at the meteorological station. A continuous snow cover above 0.1 m was not present before 19 December. Most of the snow fell during snow events 1-2 January and 20-25 April. A maximum depth of 1.1 meter was reached 26 April. Snow melt took place from the end of May and was complete below the sensor by 3 July -almost a month later than in 2005 and just as late as in 1999 which has so far been the latest year regarding snow melt.

After the snow event 20-25 April, the snow depth at M2 was more than 2.5 m and the sonic ranging sensor (SR50) was buried in snow until 28 May (Fig.2.8). Also the SKYE sensor measuring light reflection (NIR and Red) from the vegetation was buried in the same period. Snow melt was complete at M2 15 July – more than a month later than in 2005.

At M3 there was 10-40 cm of snow from 7 November to 28 December but it was all blown away during heavy winds 28

Fig. 2.8. The snow and micrometeorological station M2 covered in snow 26 May 2006

M2	Month	Year	Wind speed 2.5 m m/s	Rel. hum 2.5 m %	Air temp 2.5 m °C	Soil temp -1 cm °C	Soil temp -10 cm °C	Soil temp -30 cm °C	Soil temp -60 cm °C	Soil moist -10 cm %	Soil moist -30 cm %
	Sep	2003	2.6	68.2	0.6	1.1	1.6	1.4	0.4	12.4	12.3
	Oct	2003	3.0	72.1	-8.7	-8.3	-6.8	-4.3	-1.8	4.8	4.6
	Nov	2003	4.5	76.1	-12.9	-13.1	-12.1	-10.2	-6.9	4.0	3.2
	Dec	2003	2.9	65.2	-23.9	-9.2	-8.9	-8.2	-7.2	4.4	3.3
	Jan	2004	(3.8)	(-65)	(-20.7)	(-9.8)	(-9.4)	(-8.7)	(-7.5)	(4.3)	(3.3)
	Feb	2004									
	Mar	2004	3.0	75.8	-17.3	-11.1	-10.7	-10.1	-9.0	4.1	3.1
	Apr	2004	3.8	78.4	-7.9	-8.9	-8.9	-8.7	-8.3	4.3	3.2
	May	2004	2.6	79.0	-4.3	-5.6	-5.9	-6.4	-6.8	4.6	3.5
	Jun	2004	2.1	82.7	2.2	3.7	2.5	0.6	-1.6	27.1	17.5
	Jul	2004	2.5	77.0	6.8	9.8	8.4	5.6	0.7	20.0	17.1
	Aug	2004	2.2	80.0	5.6	7.9	7.1	5.1	1.6	17.2	16.2
	Sep	2004	3.1	76.0	0.1	1.2	1.5	1.3	0.5	15.3	14.9
	Oct	2004	3.0	69.3	-7.9	-8.1	-7.0	-4.6	-1.7	5.9	5.2
	Nov	2004	3.2	66.4	-17.6	-19.1	-17.9	-15.0	-9.7	4.0	2.8
	Dec	2004	4.1	67.6	-18.0	-18.1	-17.4	-15.7	-12.4	4.0	2.7
	Jan	2005									
	Feb	2005									
	Mar	2005									
	Apr	2005									
	May	2005									
	Jun	2005	2.1	85.9	2.5	5.4	3.9	1.7	-1.1	29.2	17.6
	Jul	2005	2.6	77.1	6.8	9.8	8.5	6.1	1.3	23.5	18.6
	Aug	2005	2.9	71.7	4.7	7.0	6.3	4.7	1.7	17.9	15.6
	Sep	2005	1.8	70.7	-1.7	-0.6	0.3	0.7	0.3	13.7	12.9
	Oct	2005	2.4	68.3	-13.1	-13.3	-11.2	-8.0	-3.8	5.0	3.8
	Nov	2005	2.2	73.6	-15.7	-12.9	-12.2	-10.8	-8.3	4.7	3.2
	Dec	2005	2.5	75.6	-14.9	-9.7	-9.3	-8.6	-7.5	5.1	3.4
	Jan	2006	2.2	76.4	-14.4	-8.3	-8.1	-7.8	-7.2	5.2	3.6
	Feb	2006									
	Mar	2006	2.7	72.2	-20.4	-9.5	-9.1	-8.6	-7.8	5.1	3.4
	Apr	2006	4.5	78.2	-9.7	-9.2	-9.0	-8.6	-7.8	5.1	3.4
	May	2006	1.5	81.3	-3.1	-7.0	-7.1	-7.1	-7.1	5.3	3.6
	Jun	2006	1.4	85.4	0.4	-0.2	-0.6	-1.1	-3.1	16.6	8.1
	Jul	2006	4.1	78.7	5.5	7.3	5.5	2.7	-0.4	31.8	16.3

M3	Month	Year	Wind speed 1.5 m m/s	Rel. hum 1.5 m %	Air temp 1.5 m °C	Soil temp -1 cm °C	Soil temp -10 cm °C	Soil temp -30 cm °C	Soil temp -60 cm °C	Soil moist -10 cm %	Soil moist -30 cm %
	Sep	2003	3.0	69.2	-1.8	-1.1	0.4	0.9	0.6	23.7	28.2
	Oct	2003	3.1	63.6	-8.7	-8.7	-6.0	-4.0	-1.9	10.6	13.4
	Nov	2003	4.7	70.0	-13.0	-11.6	-10.3	-9.1	-7.5	9.4	11.5
	Dec	2003	2.5	55.2	-20.6	-18.7	-16.9	-15.2	-12.7	7.7	10.2
	Jan	2004	(5.2)	(62.1)	(-19.3)	(-19.6)	(-18.3)	(-17.3)	(-15.6)	(7.2)	(9.8)
	Feb	2004									
	Mar	2004	3.7	69.3	-15.6	-16.9	-17.0	-16.9	-16.4	7.4	9.6
	Apr	2004	5.3	73.1	-9.0	-10.5	-11.3	-11.9	-12.6	9.1	10.7
	May	2004	2.6	72.7	-4.9	-2.9	-4.8	-6.0	-7.4	14.5	12.6
	Jun	2004	2.2	78.0	2.4	8.3	6.1	2.5	-0.9	43.9	39.3
	Jul	2004	2.5	67.5	7.3	9.8	8.6	6.4	3.2	35.4	36.2
	Aug	2004	2.1	73.8	4.9	6.6	6.1	4.9	3.0	33.6	37.4
	Sep	2004	3.5	70.3	-1.6	-1.3	0.3	0.6	0.4	23.9	30.5
	Oct	2004	3.4	58.7	-7.9	-9.4	-6.3	-4.0	-1.8	10.8	13.6
	Nov	2004	3.5	53.5	-16.0	-18.9	-16.6	-14.4	-11.4	7.7	9.9
	Dec	2004	5.2	56.0	-17.1	-19.9	-18.8	-17.6	-15.7	7.0	9.0
	Jan	2005	6.4	51.4	-12.7	-15.5	-15.3	-15.0	-14.3	8.0	9.5
	Feb	2005									
	Mar	2005									
	Apr	2005									
	May	2005									
	Jun	2005	2.1	76.5	4.0	8.3	6.0	2.2	-1.2	39.4	33.5
	Jul	2005	2.9	71.9	6.8	9.3	8.4	6.1	3.0	37.6	39.2
	Aug	2005	3.0	68.6	3.0	4.6	4.5	3.7	2.3	34.5	33.6
	Sep	2005	3.0	63.9	-3.5	-2.4	-0.7	0.0	0.1	23.9	28.1
	Oct	2005	3.6	53.0	-11.8	-13.0	-10.2	-7.8	-4.7	11.0	14.0
	Nov	2005	3.4	65.8	-14.0	-14.4	-13.4	-12.4	-10.7	9.9	12.3
	Dec	2005	5.0	64.1	-12.7	-13.0	-12.1	-11.5	-10.6	10.4	12.4
	Jan	2006	6.7	64.2	-13.4	-14.7	-14.0	-13.4	-12.3	9.8	11.9
	Feb	2006									
	Mar	2006	3.4	58.2	-17.7	-18.3	-17.6	-17.1	-16.1	8.4	10.8
	Apr	2006	5.2	65.3	-8.8	-12.8	-13.5	-13.8	-13.9	9.9	11.6
	May	2006	3.2	68.6	-3.4	-8.8	-9.4	-9.8	-10.3	11.1	12.6
	Jun	2006	1.7	73.3	1.2	3.1	0.1	-2.4	-4.6	24.1	21.3
	Jul	2006	2.5	68.8	6.9	11.1	8.9	5.7	1.7	41.6	42.5

Table 2.6. Monthly mean values of selected meteorological parameters from M2 (17 m a.s.l.) and M3 (420 m a.s.l.) from September 2003 to July 2006. Values from January 2004 are in brackets as they are based on data from 1-27 January for M2 and 1-23 January for M3. Due to malfunction, no data are obtained in the period from 6 January to 20 May 2005 at M2 and from 8 February to 22 May 2005 at M3. Likewise there are no values for February 2006 due to short drop outs of data at both stations

December. After a period with almost no snow on the ground a continuous snow cover was present from 14 March to 21 June with a maximum snow depth of 68 cm after the snow fall 20-25 April. Snow melt was complete at M3 on 21 June (Fig 2.6).

During the ablation period, snow depths were measured in the gridnet ZEROCALM-1 every week to see the spatial variation inside a relatively homogenous 100x100 m site with 121 grid nodes. When the last measurement was performed 26 June, 21 of the grid nodes were free of snow and the maximum snow depth was 51 cm.

Between 28 May and 30 May 2006, "end of winter" snow depth were measured along two main transects; SNM starting from Lomsø following a line along the snow stakes in the valley and SNZ following the ZERO-line from the old delta up to M3, 420 m a.s.l. (Fig. 2.1). Snow depths were measured for every 20 meters and data are available along with GPS position and altitude for each point. During the ablation period these measurements were repeated every week at SNM (last measurements were performed 26 June) and SNZ was re-surveyed once (10 June).

	2003	2004	2005	2006
Jan		–	–	48.6
Feb		–	–	–
Mar		56.0	–	67.3
Apr		29.1	–	46.1
May		30.5	–	36.4
Jun		45.0	57.4	53.1
Jul		47.9	46.4	58.8
Aug		34.2	19.4	
Sep	10.0	16.9	14.2	
Oct	35.9	41.8	55.9	
Nov	45.6	66.8	63.8	
Dec	79.4	60.6	56.7	

Table 2.7. Percent of the temperature records where the temperature is higher at M3 (420 m a.s.l.) than at M2 (17 m a.s.l.)

Snow cover

The extent of spring snow cover at Zackenberg was among the highest observed. On 10 June, the snow cover was much more extensive than previous years in Zackenbergdalen. A more detailed analysis of the snow extent in different subzones based on the photos from 10 June will be reported in the next annual report together with updated snow depletion curves for 2005 and 2006. Right now we are in a process where the new cameras on Nansenblokken have been calibrated and new software will be applied during the coming year to obtain snow cover distribution data for the entire Zackenberg valley.

The snow cover extension in the valley at the "end of winter" is shown in the photo from Nansenblokken 30 May (Fig 2.9).

A multispectral camera used to observe the greenness of the vegetation in the valley was installed 1 June and two daily photos were captured up to 27 August where the camera was removed. The digital camera covering the northern part of the valley (Camera 3) was replaced 1 June with a new model (ECUCIG Mklla) modified by technicians at Department of Geography and Geology.

Snow density

Snow densities were measured in the end of May at all permanent soil sites covered by snow in order to calculate snow water equivalent (SWE). Except from Sal-1, all soil sites were covered in snow at the end of May. In ZEROCALM-1, densities were measured on a regular basis throughout the ablation period and a snow pit was made 2 June. The snow was isothermal above 30 cm and -4°C at the ground surface.

In ZEROCALM-2, a snow pit was made 31 May and densities were measured for layers of 50 cm and temperatures measured for every 10 cm throughout the 275 cm deep profile showing isothermal conditions above 175 cm and -7°C at the bottom. No significant ice layers were observed in the snow.

Active layer depth

Development of the seasonal active layer (the layer above the permafrost that annually experiences freeze and thaw) starts

Table 2.8. Key figures describing the amount of snow in 9 winters; the maximum snow depth during the winter and the date at which it is reached, the date when the snow depth reaches 0.1 m in the beginning of the winter, and the date in spring when the depth gets below 0.1 m due to melting.

Winter	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006
Max. snow depth, meter	0.88	1.30	0.49	0.68	1.33	0.60	0.69	0.73	1.10
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr	13 Apr	12 Feb	26 Apr
Snow depth exceeds 0.1m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	6 Dec	24 Nov	27 Dec	19 Dec
Snow depth is below 0.1m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul

Fig. 2.9. Snow cover in Zackenbergdalen 30 may 2006. View from Nansen-blokken 480 m a.s.l..

as soon as snow disappears from the ground and air temperatures get positive. The thaw rate of the soil was monitored throughout the season at two grid-plots; the homogenous ZEROCALM-1 grid (ZC-1) and the heterogeneous ZEROCALM-2 grid (ZC-2) (Fig. 2.10). A detailed description of the two sites was given in section 5.1.12 in Meltofte and Thing (1997). In ZC-1, the first grid node was free of snow 20 June and snow melt was complete 5 July. At the end of the season, the maximum

Data from the ZEROCALM-sites are reported to the circumpolar monitoring programme CALM (Circumpolar Active Layer Monitoring-Network-II (2004-2008) that is maintained by the University of Delaware, Center for International Studies (www.udel.edu/Geography/calm).

Point measurements of thaw depth progression were also measured throughout the season at all the soil water sites.

Table 2.9. Maximum average active layer depth in cm. Measured in ZEROCALM-1 and ZEROCALM-2 late August, 1997-2006

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
ZEROCALM-1	61.7	65.6	60.3	63.4	63.3	70.5	72.5	76.3	79.4	76.0
ZEROCALM-2	57.4	59.5	43.6	59.8	59.7	59.6	63.4	65.0	68.6	67.6

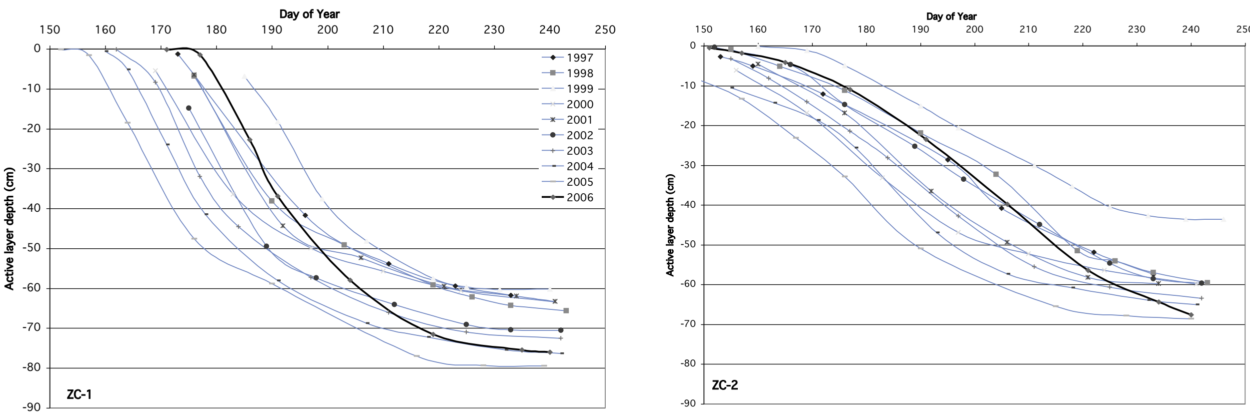
thaw depth in ZC-1 reached an average of 76 cm (Table 2.9). In ZC-2, only two grid nodes in the NE-corner were free of snow when we arrived 26 May and the maximum thaw depth was 10 cm. Nevertheless, the thaw depth in ZC-2 reached an average of 67.6 cm at the end of the season which is 24 cm deeper than in1999 where snow melt conditions were similar. Besides the higher air temperatures in August 2006, the seasonal snow patch that affects the melt rate in ZC-2 disappeared 9 August 2006 whereas it persisted throughout the summer in 1999. Still, the melt rate in the end of August was very high compared to previous years.

Soil temperature

A new soil temperature installation was established at the climate station in August 2006 in order to replace the old sensors as several of them were not reliable anymore. Since 2004, it has only been possible to validate some of the soil temperatures. The new sensors were installed at similar depths as in the old setup (0, 2.5, 5, 10, 20, 40, 60, 80, 100, 130 cm).

Besides the main soil temperature profile, soil temperatures have been automatically logged since 2005 at the soil-and micrometeorological station M4 and since 2003 at the two snow- and micrometeorological stations M2 and M3. Mean monthly

Fig. 2.10. Thaw depth progression in ZERO-CALM-1 and ZEROCALM-2, 1997-2006. Thaw depth progression is based on 8 and 10 re-measurements during the season in ZC-1 and ZC-2, respectively.



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
West pond		4.6	Dry	5.6	10.6	30.5	8.6	2.6	9.6	<26.5	Dry	3.6
East pond		3.6	Dry	6.6	16.6	1.6	6.6	3.6	12.6	28.5	22.5	6.6
South pond		<3.6	30.5	7.6	12.6	1.6	8.6	3.6	8.6	<26.5	<21.5	8.6
Lomsø		4.7	2.7	8.7	10.7	1.7	4.7	30.6	29.6	22.6	17.6	3.7
Rivulets		<6.6	11.6	11.6	15.6	4.6	10.6	4.6	3.6	31.5	4.6	13.6
Zackenbergelven	<26.5	<3.6	4.6	10.6	20.6	8.6	8.6	4.6	30.5	1.6	3.6	12.6
Young Sund (Zac.)		13.7	19.7	14.7	14.7	8.7	13.7	1.7	5.7	1.7	3.7	14.7
Young Sund (all)	12.7	13.7	22.7	22.7	24.7	17.7	23.7	8.7	8.7	8.7	7.7	23.7

Table 2.10. Visually estimated dates of 50% ice cover on selected ponds and lakes around the research station, together with start of running water in rivers and break up of the fjord ice in Young Sund during 1995- 2006. "West pond" and "East pond" are the two ponds in Gadekæret north of the runway, "South pond" is the major pond in Sydkærene south of the runway. "Rivulets" are the streams draining the slopes of Aucellabjerg through Rylekærene. Zackenbergelven gives the initial date of genuine flow in the river. Young Sund break up is divided between break up of the fiord ice off Zackenbergdalen and in the fiord in general. The 50% ice cover date for Lomsø is tentative, as it is estimated from the research station.

values from the latter are given in Table 2.6 and mean daily soil temperatures from the soil surface are shown in Fig. 2.6.

Temperature in different settings and altitudes

GeoBasis operates a total of 40 TinyTag dataloggers for year around temperature monitoring in different altitudes and different geomorphologic settings in the periglacial landscape of Zackenberg. Positions and a short description of the sites are given in the GeoBasis manual.

The TinyTag (T5) installed in 2004 on top of Domebjerget (1278 m a.s.l.) had stopped logging 25 April 2006 when a snow storm broke down the sensor house from the mast. It was not re-installed as a new meteorological station (M6) was installed at the top of Domebjerget this summer.

Break up of the fjord ice in Young Sund

The fiord ice between Zackenbergdalen and Clavering Ø broke up during 12-15 July but not until 23 July, there was open water all the way to the sea (Table 2.10). This is in line with observations before 2002 but in contrast to the last four years of early break up. Around Sandøen in the outer part of Young Sund ice break-up was complete 26 July.

2.3 River water discharge and chemistry

Spring break up of Zackenbergelven and secondary streams

Zackenbergelven broke up 12 June 2006, when water from Lindemansdalen started to run. This is late compared to the last ten years (Table 2.10). When a small flood passed the hydrometric station early in the morning 14 June it indicated the break-up of water from Store Sødal. The first water samples from the tributaries to Zackenbergelven were collected 13 June (Table 2.11). At that time some water was running in channels in the snow from Aucellabjerg and from Palnatokebjerg but drainage from the fen area (Rylekær and Tørvekær) was still absorbed in the snow.

In late June, several hundreds/thousands of dead arctic chars were flushed through the river system. Dead fish were found along the river and hundreds were caught on wires and other obstacles at the hydrometric station (Fig. 2.11). The arctic chars must have been caught in a blind section of the river when they headed from the fiord to the lakes in late August 2005. When water started to run and the river bed melted all the dead fish were flushed out.

Zackenbergelven

The drainage basin for Zackenbergelven includes Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km^2, of which c.106 km^2 are covered by glaciers (Fig 2.12 in Klitgaard, Rasch and Caning 2006).

The hydrometric station was established at the lower part of the river, at the west side (Meltofte & Thing 1996). In 1998 the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried beneath a thick snowdrift each winter. In 2005, the station was flushed away in a flood and 5 August it was re-build at a position 30 m south of the river crossing still on the eastern side of the river.

Suspended sediment (mg/l)

	Store Sødal	Lindeman	PalnatokeNW	PalnatokeE	AucellaN	AucellaS	Rylekær
13 Jun	105	140	50	ND	28	Dry	Dry
28 Jun	80	304	207	91	154	1,859	<2
11 Jul	58	39	148	2	31	1,060	10
26 Jul	71	115	703	2	850	1,706	<2
8 Aug	59	15	450	3	87	110	<2
14 Aug	63	27	800	2	402	175	<2
21 Aug	61	11	252	Dry	101	149	<2

Organic matter as part of total suspended sediment (%)

	Store Sødal	Lindeman	PalnatokeNW	PalnatokeE	AucellaN	AucellaS	Rylekær
13 Jun	8	8	12	ND	27	Dry	Dry
28 Jun	9	6	9	36	11	7	ND
11 Jul	11	18	11	ND	25	7	ND
26 Jul	8	9	8	ND	8	8	ND
8 Aug	10	30	10	ND	12	11	ND
14 Aug	6	9	8	22	9	9	ND
21 Aug	6	11	7	Dry	10	9	ND

Conductivity (µS/cm)

	Store Sødal	Lindeman	PalnatokeNW	PalnatokeE	AucellaN	AucellaS	Rylekær
13 Jun	14	119	84	51	58	Dry	Dry
28 Jun	10	39	25	16	30	44	22
11 Jul	9	40	26	28	42	51	43
26 Jul	10	56	25	66	69	68	61
8 Aug	9	98	36	115	129	115	63
14 Aug	10	112	36	133	116	110	51
21 Aug	10	127	43	Dry	152	135	49

DOC (mg/l)

	Store Sødal	Lindeman	PalnatokeNW	PalnatokeE	AucellaN	AucellaS	Rylekær
13 Jun	0.8	0.7	5.9	ND	5.9	Dry	Dry
28 Jun	1.1	1.2	0.7	2.0	1.6	0.6	2.6
11 Jul	1.1	0.7	0.8	2.6	2.4	1.0	3.1
26 Jul	0.8	0.9	1.1	1.7	1.7	1.1	2.2
8 Aug	0.4	0.8	0.1	0.9	0.3	0.4	2.9
14 Aug	0.7	0.6	0.3	1.0	1.0	0.7	2.7
21 Aug	3.9	1.2	0.4	Dry	1.0	0.7	2.5

NH4-N (µg/l)

	Store Sødal	Lindeman	PalnatokeNW	PalnatokeE	AucellaN	AucellaS	Rylekær
13 Jun	24.4	32.8	28.4	ND	46.9	Dry	Dry
28 Jun	23.0	28.6	36.0	35.6	26.2	19.1	29.5
11 Jul	29.3	25.7	26.1	31.0	25.4	26.0	21.9
26 Jul	26.2	24.9	41.7	28.9	27.8	26.2	22.6
8 Aug	27.5	21.5	25.5	22.2	21.1	23.9	21.0
14 Aug	29.8	19.1	25.7	26.8	24.2	23.2	25.4
21 Aug	36.7	25.7	20.6	Dry	24.9	26.5	31.5

DTN (µg/l)

	Store Sødal	Lindeman	PalnatokeNW	PalnatokeE	AucellaN	AucellaS	Rylekær
13 Jun	232.3	268.6	475.7	ND	698.1	Dry	Dry
28 Jun	281.2	274.0	162.2	345.1	212.7	88.8	348.2
11 Jul	270.0	182.1	217.7	347.1	177.8	63.2	390.2
26 Jul	177.3	280.8	280.2	487.5	321.6	122.4	207.7
8 Aug	92.7	65.0	91.4	135.7	78.7	107.7	204.4
14 Aug	285.1	61.8	76.5	173.5	104.8	96.0	672.1
21 Aug	800.2	197.0	122.0	Dry	330.7	155.2	604.8

Table 2.11. Suspended sediment, organic matter in percent of total suspended sediment, conductivity, DOC, NH_4-N and DTN in water sampled from main tributaries to Zackenbergelven (streams from Store Sødal, Lindeman, PalnatokeNW, PalnatokeE, AucellaN, AucellaS and Rylekær. ND = No data. Dry = No water running.

Fig. 2.11. Dead Arctic chars caught on a wire when they were flushed through the river during spring break-up.

At the station, water level, water temperature, and air temperature are logged automatically every 15 minutes. The water level is both measured by use of a sonic range sensor and by two pressure sensors. Discharge data for 2006 are based only on data from the sonic range sensor. The measured water level is recalculated to meter above sea level, which can be transformed to a discharge using an established relation between water level and discharge (a Q/h-relation).

Q/h-relation

A new Q/h-relation has been calculated after a flood 25 July 2005 changed the river cross profile (Fig 2.15 in Klitgaard, Rasch and Caning 2006). To establish a new Q/h-relation discharges have been manually measured by use of a current meter and corresponding water levels. Since the flood, 14 discharge measurements ranging from 10.3 to 46.0 m^3/s have been carried out under ice free conditions. As the cross profile has a very deep part where the water pressure makes manual measurements impossible at high water levels it has only been possible to measure across the total profile in 8 of the discharge measurements covering a range from 10.3 to 33.1 m^3/s. The discharge in the remaining 6 measurements has been calculated by use of two main assumptions:

1) It is assumed, that the cross profile has been stable after the flood and until the station was left in late August 2006. Depth measurements across the profile from August 2006 have been used to estimate the depths in the deep part of the river where no measurements could be performed.

2) It is assumed, that the velocities in the part of the cross section where no

Table 2.12. Total and monthly discharge in Zackenbergelven, corresponding water loss for the drainage area (514 km²) and precipitation measured at the climate station for the years 1996-2006. 1) The hydrological year is set to 1 October previous year to 30 September present year.
2) Include estimation based on photos and manual readings in the period from 25 July to 5 august where a new hydrometric station was installed.
3) Data from the flood in late August are included.

Hydrological year 1)	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Total Discharge, mill m³	132	188	232	181	150	137	338	189	212	200 2)	>169 3)
June	43	45	50	41	41	53	143	71	46	66	31
July	67	80	98	123	61	47	150	71	100	100	98
August	21	61	78	17	47	34	46	43	64	34	40
September	1	2	4	0	0	3	0	4	2	??	??
Water loss, mm	257	366	451	352	292	267	658	368	412	389	>329
Precipitation, mm	239	263	255	227	171	240	156	184	279	258	203
Total annual transport											
Suspended sediment (ton)		29,444	130,133	18,716	16,129	16,883	60,079	18,229	21,860	71,319	27,214
Suspended organic matter (ton)		1,643	11,510	2,297	1,247	1,098	3,267	1,351	1,388	3,475	1,807

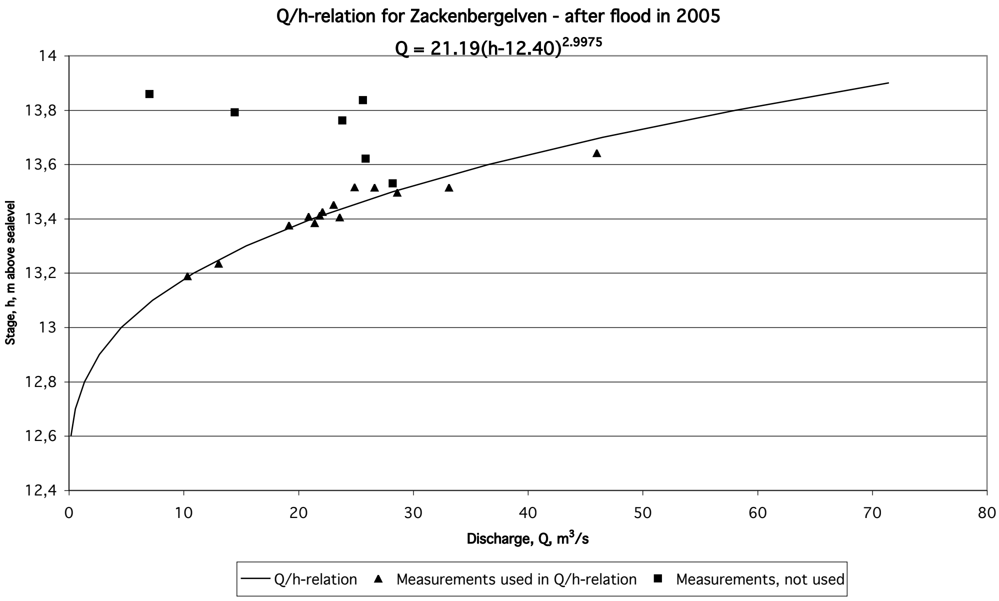


Fig. 2.12. Water level – discharge relation curve (Q/h-relation) for Zackenbergelven at the hydrometric station after 25 July 2005. The coefficient of correlation (R^2) for the curve is 0.97.

measurements were carried out scale to the velocities just outside this part. For all complete discharge measurements, the velocity at each position in the cross section is scaled with the velocity measured approximately 37 meter from a fixed point. A best fit is drawn through these points and this is used to calculate the velocities where no measurements were made.

A Q/h-relation has been derived based on the 14 discharge measurements and the assumption that the discharge is zero when the water level decreases to 12.40 m a.s.l., corresponding to the bottom of the river (Fig 2.12). Due to the limited range of discharge measurements and the incomplete measurements described above, the Q/h-relation is preliminary and will be re-evaluated when further measurements have been carried out.

River water discharge

Total discharge in 2005 has now been updated using the new Qh-relation. In the period from 3 June to 24 August the amount of water drained from the catchment is estimated to 200 mio.m³ (Fig. 2.13 and Table 2.12).

In 2006, the total water discharge in Zackenbergelven from 12 June to 27 August was c. 169 mio. m³ (Fig. 2.14 and Table 2.12). In the first period – from the river started flowing 12 June and until 26 June – the riverbed and banks were covered in ice/snow and the Q/h-relation

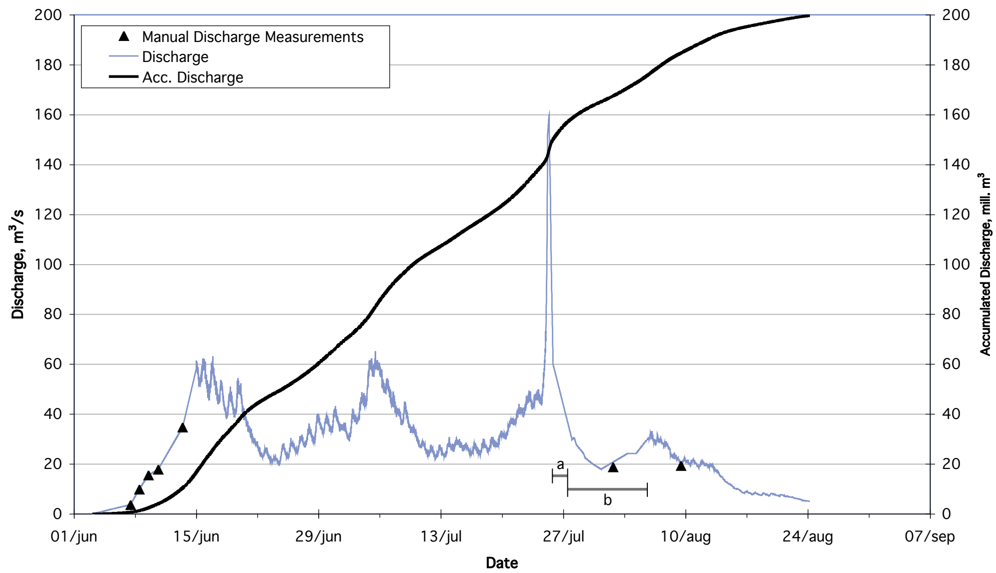


Fig. 2.13. Discharge in Zackenbergelven 2005. (a) As the hydrometric station was flushed away, the peak discharge is based on photos (b) Discharge in the period from 27 July to 5 August is based on manual readings on a new stage level.

therefore not valid. Instead, the discharge in this period is approximated by linear increase from zero to the discharge found at the manual measurement 17 June and again by linear interpolation between the manual measurement 19 June, 21 June, 22 June, 23 June and 24 June.

A large flood was observed in late August just before the station was left. During the evening 29 August the river discharge increased dramatically. From 15:00 to midnight the water level at the hydrometric station increased from 25 cm to 188 cm. The water level peaked at midnight and showed a steady decrease until the morning 30 August. No further observations are available, as the station was left for the winter the same morning. Most likely, the flood was caused by collapse of an ice dammed lake in the glaciers on A.P. Olsen land. According to the current Q/h-relation the peak discharge was approximately 220 m^3/s. As the calculated discharge during the flood is based on an extrapolation of the Q/h-relation far beyond the range of manual discharge measurements it should be regarded as a very rough estimate.

Daily discharge data from Zackenberg are being reported to the Global Runoff Data Centre (GRDC) who maintains and promotes a global database on river discharge (www.grdc.bafg.de).

Suspended sediment

Suspended sediment concentration for 2005 has now been updated using the discharge data calculated from the new Qh-relation. Due to the flood in July and the relatively high sediment concentrations afterwards, the total transport of 71,319 ton was the second highest recorded so far (Table 2.12).

In 2006, water samples were collected both in the morning 8:00 and in the evening 20:00. Except for a few occasions the suspended sediment concentration was highest in the evening (Fig 2.15 c). The highest concentration of the season was 5,566 mg/l measured a few hours before peak discharge 29 August. Additional water samples were collected every second hour during 4 diurnal observations 6-7 July, 12-13 July, 20-21 July, 12-13 August (Fig 2.16).

In the period from 12 June to 29 August a total amount of 27,214 ton suspended sediment was transported from the Zackenberg drainage basin to the fiord (Tabel 2.12). All values of annual sediment transport in Table 2.12 are based on concentrations measured in water sampled at 08:00 assuming this can be used as a diurnal mean value. From the majority of the diurnal measurements performed throughout the years we know, that this assumption often fails. If the calculation for 2006 is based on concentrations measured 8:00 (used from midnight to midday) and concentrations measured 20:00 (used from midday to midnight) the total amount of suspended sediment is 50,651 ton which is almost twice as much as the value solely based on the concentrations measured 8:00. Both estimates include the transport during the flood and as mentioned in the above section, the high discharges during the peak flood are a

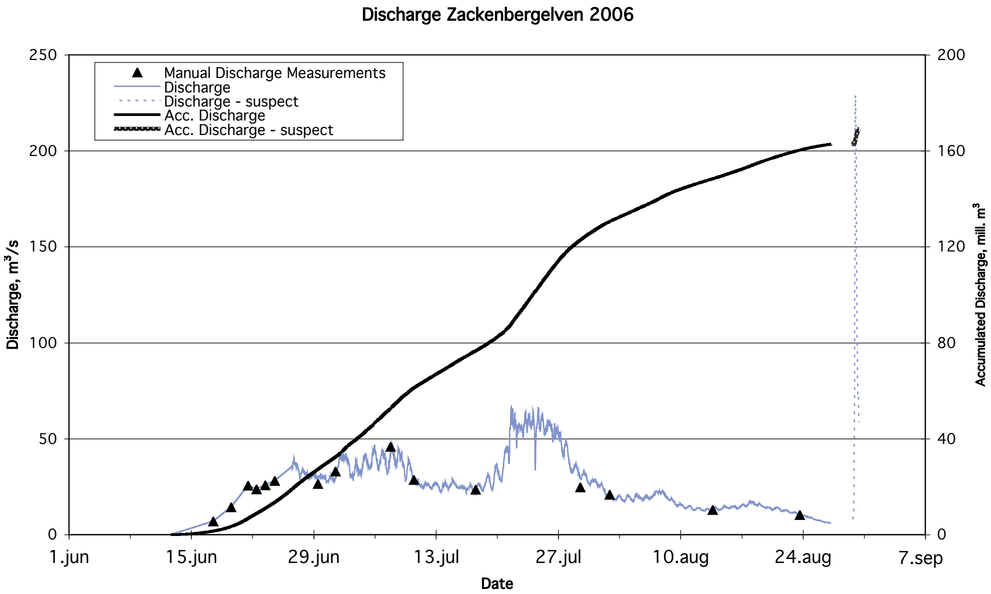


Fig. 2.14. River water discharge in Zackenbergelven during summer 2006.

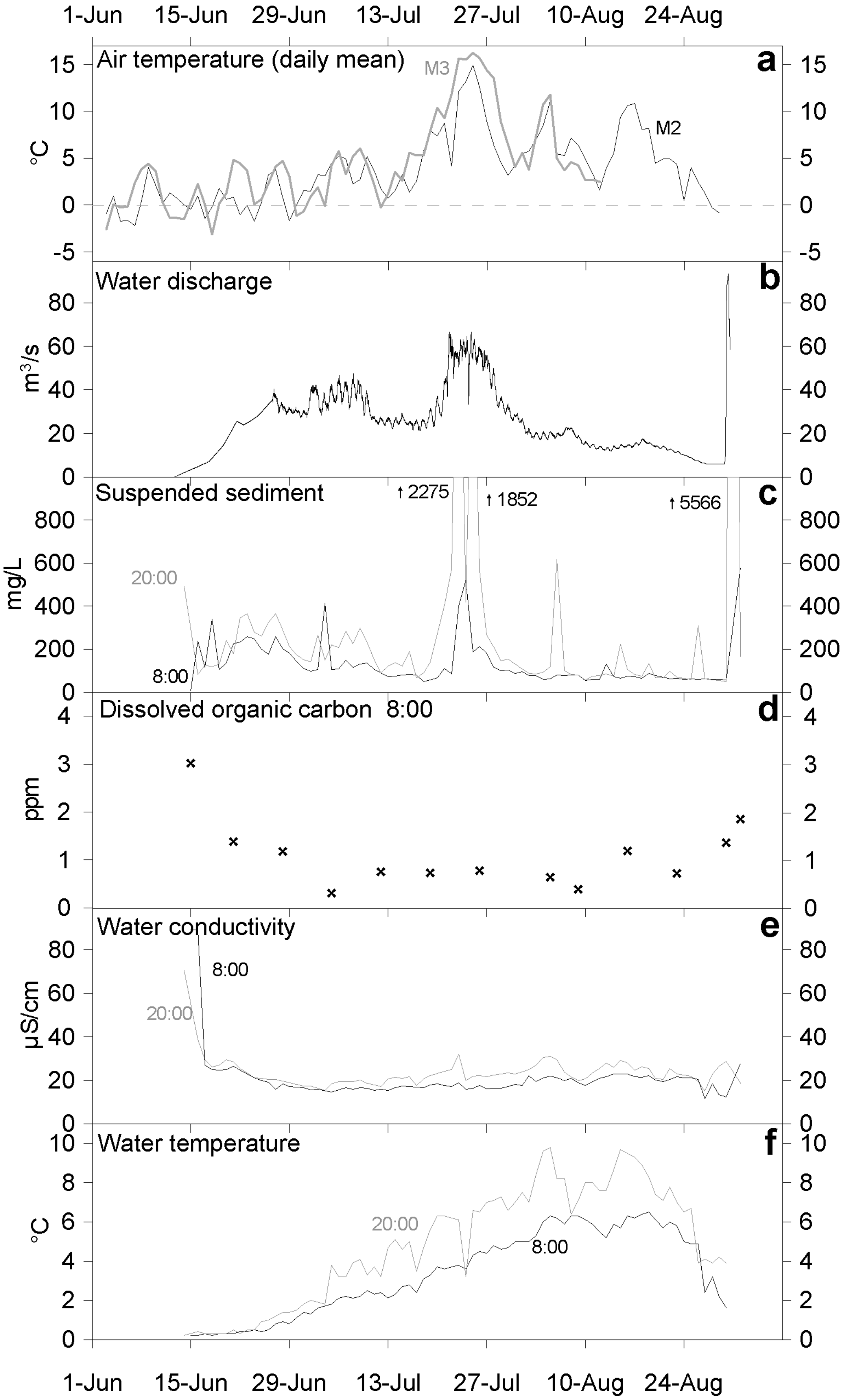


Fig. 2.15. a) Daily mean air temperatures at M3 420 m a.s.l. and at M2 17 m a.s.l. b) water discharge, c) concentration of suspended sediment, d) dissolved organic carbon e) conductivity and f) water temperature, in Zackenbergelven 2006.

very rough estimate and therefore the total transport of sediment is also subject to some uncertainties. The transport during the flood (midday 29 August to 30 August in the morning) constitutes 3,000-11,000 tons depending on the method used.

Suspended sediment and solutes in tributaries to Zackenbergelven

In 2006, water was sampled seven times from the main tributaries to Zackenbergelven. Location of sample sites is given in Fig. 2.1. Water temperature and conductiv-

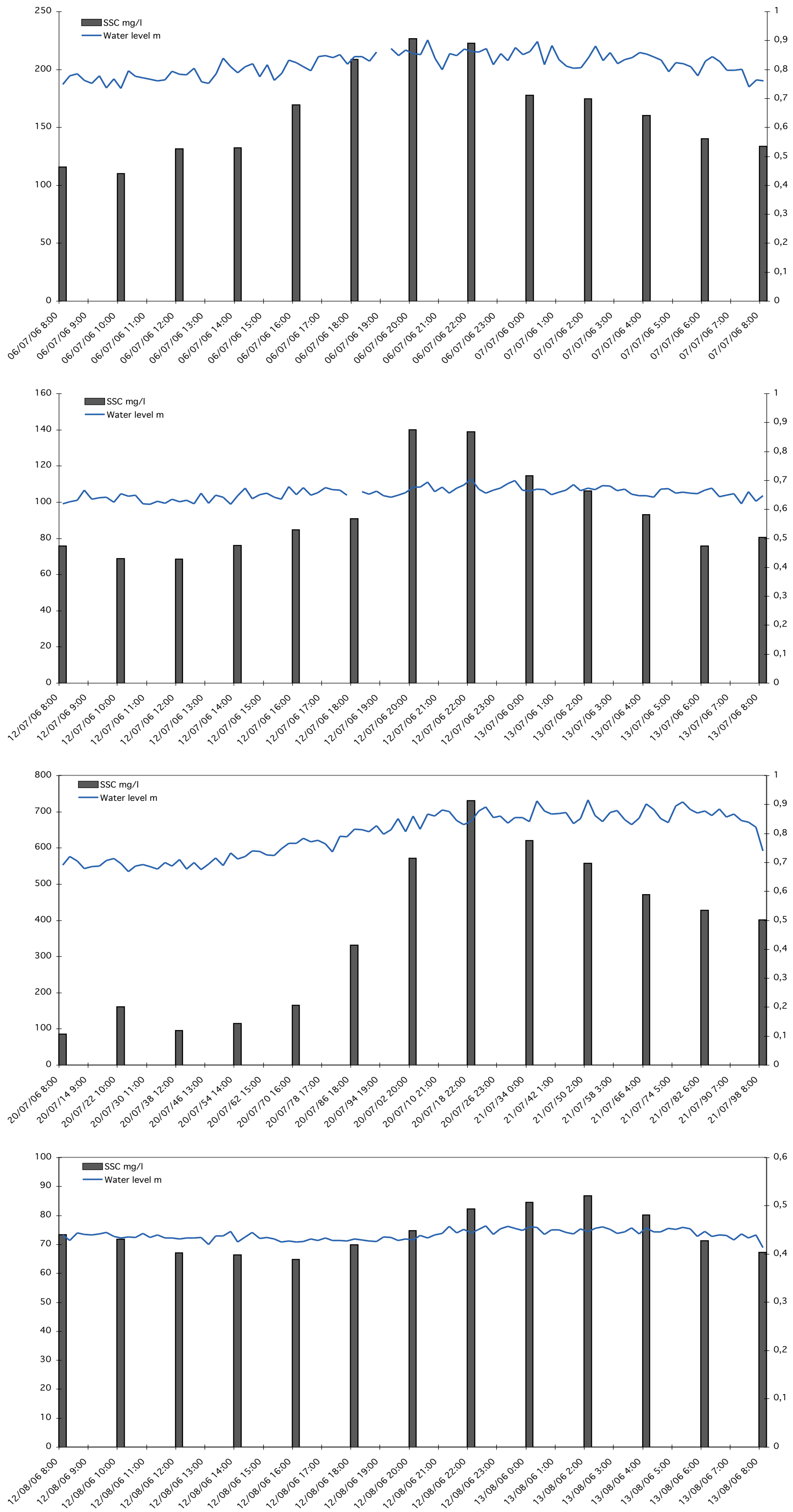


Fig. 2.16. Corresponding levels of suspended sediment concentration (SSC) and water discharge during 4 diurnal samplings.

ity were measured on location, whereas water chemistry, suspended sediment and organic matter concentration were determined from collected samples (Table 2.11).

A CTD diver, capable of measuring water level, water temperature and conductivity, was installed c. 300 m upstream from the junction between Lindemanselven and Store Sødal (UTM: 511662 E, 8269094 N, 82 m a.s.l.). The diver was installed 2 July when the riverbed and banks were free of snow and data was logged continuously every 15 minutes until 21 August where the diver was removed. The discharge ranged from 0.2-26 m^3/s with an average of 4.6 m^3/s. The highest discharge of the season was measured 21 July 18:00 during a period with high temperatures. A pronounced diurnal variation is observed throughout the season with a maximum in the evening between 18:00 and 20:00 and a minimum in the morning between 8:00 and 10:00.

Conductivity ranged from 12 to100 µS/cm with the highest conductivities found at the end of the season when the discharge decreased. Also the diurnal amplitude in the conductivity was increasing throughout the season from variations of about 5 µS/cm in the early season to variations of up to 25 µS/cm later in the season.

2.4 Precipitation and soil water chemistry

Precipitation

During the 2006 season, water from the precipitation collector was sampled at 3 occasions. After arrival (26 May) and after rain events 2 July and 31 July.

Soil Moisture

Soil moisture at 10 cm and 30 cm below soil surface are measured year around at the snow- and micrometeorological stations M2 and M3 (Fig. 2.6). Since August 2005, soil moisture 5, 10, 30 and 60 cm below the soil surface has also been logged continuously at M4 (located next to M1 on Fig 2.1) In addition to these continuous measurements, soil moisture is being monitored manually twice a week throughout the summer season at 5, 10 and 30 cm depths at the soil water plots covered by different vegetation communities (see next section). Once a week, soil moisture in the upper 5 cm is measured along two transects in ZEROCALM-2, covering the variation from the very well drained barren ground in the upper end to the water soaked grassland in the lower end. Finally, soil moisture from 0-60 cm is continuously logged at 30 minutes intervals throughout the summer season at the micrometeorological station M4.

Soil water

Soil water is collected from various depths at five characteristic soil water regimes covered by the dominating plant communities in the valley. A well drained cassiope heath (K-site); a wet fen area (S-site); a dry heath site covered by Dryas (Dry1-site); a snowbed site covered mainly by Salix (Sal2-site) and finally a site covered by mixed heath vegetation (Mix1-site). A more detailed description of the sites are given in Caning and Rasch (2000) and Rasch and Caning (2004).

In 2006, soil water was collected four times during the season and the chemical composition of the soil water analysed.

2.5 Gas fluxes

Carbon dioxide flux

In order to describe the interannual variability of the seasonal carbon balance, exchange of CO_2 between a well drained heath ecosystem and the atmosphere has been measured since 2000 using eddy covariance technique. Details on the instrumentation are given in section 4.2 in Rasch and Caning (2003).

In 2006, measurements were initiated on 27 May and continued until 27 August giving a total of 93 days of measurements with only few interruptions. By the end of the season less than 1% of the data were lost due to malfunction, maintenance and calibration.

The temporal variation in daily net exchange of CO_2 and mean daily air temperature, during the three months of continuous measurements is shown in Fig 2.17. The sign convention used is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative. The sum of the two processes i.e. uptake of CO_2 by plants from photosynthesis and loss due to microbial

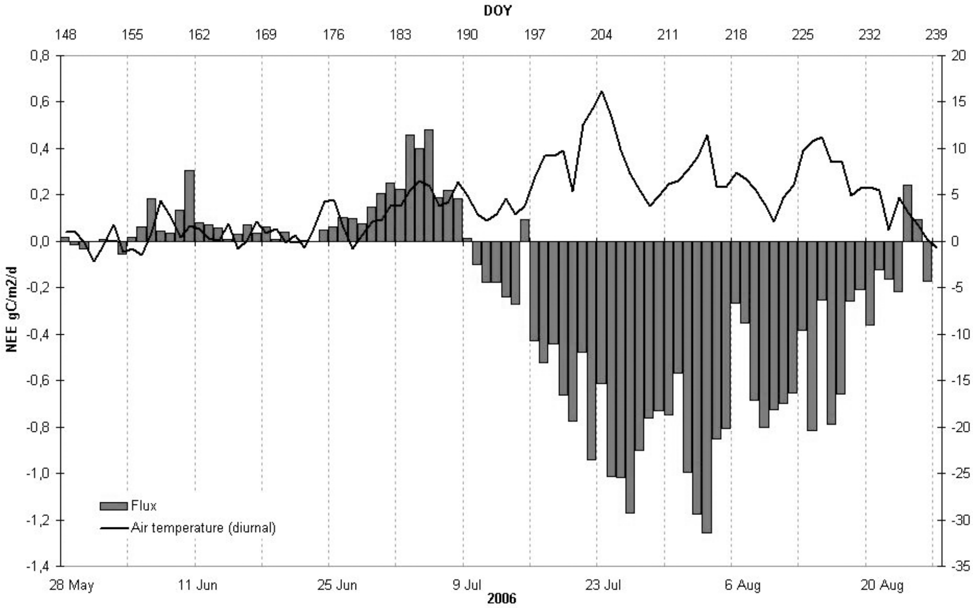


Fig. 2.17. Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the heath in 2006.

decomposition in the soil, is denoted Net Ecosystem Exchange (NEE). The uptake is governed by the climatic conditions during the growing season with solar radiation and temperature being key variables. The respiratory process is controlled by soil temperature in an exponential fashion, and also soil moisture has an effect on the respiration.

When measurements were initiated 27 May, the eddymast (3 m high) was placed on top of 115 cm snow and the snow cover in the fetch area was 100%.

In the early part of the measuring season (the end of the winter) when snow was covering the ground and diurnal air temperatures were around 0°C, the ecosystem was characterized by a small netto emission of CO_2. The small peak in the emission observed on 10 June could be related to relatively strong winds on that day -enabling a release of trapped CO_2 from the snow. During the last part of June and early part of July, the snow cover gradually disappeared and the soil respiration increased resulting in a pulse of CO_2 from the soil to the atmosphere with a maximum NEE of 0.48 gC/m^2/d were captured on 5 July (Fig. 2.17). As the ground became free of snow, the vegetation developed and a photosynthetic uptake of CO_2 started. In a few days, the photosynthetic uptake of CO_2 exceeded the respiration and from 10 July the ecosystem switched from a source of CO_2 to a sink of CO_2 –a switch that characterizes the initiation of the growing season.

The growing season lasted 45 days and was only interrupted by a single day (15 July) where respiration exceeded the photosynthesis due to cloudy and windy weather and a low level of incoming solar radiation. June and the first half of July was cold but the second half of July was warm and a diurnal mean temperature of 16.2°C was reached 23 July. This is the highest daily mean temperature recorded since the measurements from the climate station were initiated in 1996. The variations in temperatures are reflected in the pattern of the uptake of CO_2 and the growing season peaked with a maximum uptake on 3 August (Fig. 2.17). After that, the accumulation of CO_2 gradually decreased due to leaf senescence and decreasing solar radiation. By 24 August, the respiration exceeded the photosynthesis and the ecosystem turned back to a source of CO_2 -indicating the end of the growing season. Compared to previous years, the growing season was relatively short, mainly because of the late initiation due to late snow melt and low temperatures in the early summer. On the other hand the end of the growing season was later than observed before (Table 2.13). After 24 August it started to snow and the last days before the station was closed down 27 August, the ground was covered by a few centimeters of snow.

The growing season ended up with a total uptake of 26 g C/m^2 –which is a little less than measured the last three years (Table 2.13). But if the length of the growing season is considered, the average uptake per day is actually the second largest and only exceeded by the uptake in 2003.

For the measuring period in total, the

	2000	2001	2002	2003	2004	2005	2006
Beginning of growing season	25 June	6 July	2 July	28 June	23 June	17 June	10 July
End of growing season	11 August	18 august	16 August	20 August	21 August	18 August	23 August
Length of growing season	47 days	43 days	45 days	53 days	59 days	63 days	45 days
Beginning of measuring season	6 June	8 June	3 June	5 June	3 June	21 May	27 May
End of measuring season	25 August	27 August	27 August	30 August	28 August	25 August	27 August
Length of measuring season	80 days	81 days	86 days	86 days	86 days	97 days	93 days
NEE for growing season (gC m^{-2})	(-) 22.7	(-) 19.1	(-) 18.2	(-) 30.4	(-) 29.7	(-) 33.4	(-) 26.1
NEE for measuring season (gC m^{-2})	(-) 19.1	(-) 8.7	(-) 9.5	(-) 23.0	(-) 22.4	(-) 29.6	(-) 21.6
Maximum daily accumulation (gC m^{-2} d^{-1})	(-) 0.92	(-) 0.94	(-) 1.00	(-) 1.40	(-) 1.30	(-) 1.15	(-) 1.25

Table 2.13. Summary of summer season environmental variables and CO_2 exchange 2000-2006.

ecosystem also acted as a sink of carbon with a total accumulation of 21.6 g C/m^2 in the period from 27 May until 27 August. But with only three days of measurements after the ecosystem changed back to a source of CO^2, there is a serious lack of measurements from the autumn and the early winter where the system primarily act as a source and therefore could reduce the total uptake.

Methane flux

Monitoring of methane (CH_4) fluxes were implemented as part of the GeoBasis programme in 2006 in order to full fill the recommendations from ACIA. The site for methane flux monitoring was established in august 2005 in the fen area Tørvekæret (UTM: 513270mE 8265540 mN) (M5 in Fig. 2.1) where former research studies of methane fluxes have been performed in 1999-2000 (A. Joabsson, T.R. Christensen, L. Ström in Caning and Rasch 2001) and in a close-by area in 1997 (T.R. Christensen, T. Friborg in Meltofte and Rasch 1998).

The set-up consist of six transparent automatic chambers (58x58x30cm) installed in line (Fig. 2.18). Plastic tubes connect the chambers to a box where air samples are being analyzed for CH_4^- and CO_2. Methane concentrations are measured by a laser off-axis integrated-cavity output spectroscopy analyzer (Fast Methane Analyzer, Los Gatos Research, USA). Time resolution of concentration data is 1 second.

Every hour each chamber closes automatically for 5 minutes. When a chamber is closed the concentration of methane increase linearly and the trend value can be recalculated to methane flux. If a chamber does not close correctly due to strong wind or obstacles, the concentration pattern is ragged and such data is filtered out when fluxes are calculated.

The flux values (Fig. 2.19) are calculated

Fig. 2.18. The methane site in Tørvekæret

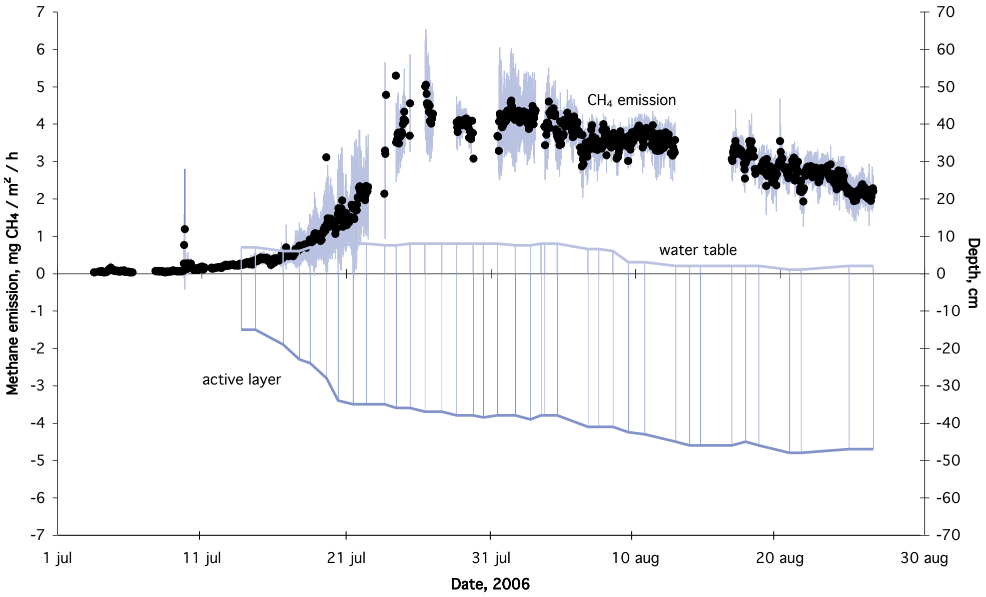


Fig. 2.19. Methane (CH_4) emission from the fen (Tørvekæret) during the summer 2006. Changes in water table and depth of active layer are read on the right axis.

from measured chamber volumes (free volume from peat surface or water table surface), air temperature and air pressure from the nearby meteorological station (section 2.1).

Due to the very late snow melt in 2006, there was still some snow in and around the chambers when measurements were initiated 3 July. Measurements continued until 26 August, when the station was closed. During the 54 days of monitoring there were a few gaps due to malfunction of instruments and power supply failures (the longest break was a 94 hour period in mid August). Only four of the six chambers were used in 2006, as two of them were damaged during winter (probably by muskoxen).

The first week of measurements showed very low, but still resolvable fluxes about 0.03 mg $CH_4/m^2/h$. A small peak (up to 0.15 mg $CH_4/m^2/h$) was registered 4 July, when snow/ice in the chambers melted. The peak observed 9 July was probably related to soil thaw and release of previously captured methane.

During the period 12-25 July the CH_4 fluxes showed an almost exponential increase related to increasing methane production (due to increasing soil temperature and active layer depth) and very low oxidation (due to high water level and dormant vascular plants). Around 25 July the picture changed – the CH_4 flux reached its maximum (about 5 mg $CH_4/m^2/h$) and started to gradually decrease. One possible explanation for this is the methane rhizospheric oxidation that started when the vascular plants began to photosynthesize. The direct effect of rhizospheric oxygen – CH_4 oxidation – may be less significant than the indirect effect – shifting redox potentials (Eh) and suppressed methanogenesis. The other explanation to the abrupt change in methane flux dynamics may be substrate limitation – if we assume that first decade of "spring" methanogenes lived on substrates, accumulated in peat from the end of the previous season.

From the end of July to the end of the measurement season, the CH_4 flux showed an almost linearly decrease (from about 5 to 2 mg $CH_4/m^2/h$). This could indicate a balance between methane production and oxidation, linked with transport through the soil and accumulation in subsurface CH_4 pools.

Unfortunately, the measurement period did not cover the whole active season and it is still a question how long the methane flux would sustain the same pattern? Does the flux curve gradually approach zero, or does it show an abrupt stop with the first freezing temperatures? Would we see other peak(s) due to imbalance between methane production and oxidation when the surface layer freezes while the lower horizons are still active?

From 3 July to 26 August 2006 a total of 2.17 ± 0.45 g CH_4/m^2 (1.63 ± 0.34 g C/m^2) was emitted but the real budget for the growing season and the real annual budget can be up to 50% higher due to the autumn fluxes.

2.6 Geomorphology

Landscape monitoring based on photos of different dynamic landforms such as talus slopes, rock glaciers, mud slides, frost boils, gullies, thermo karsts, beach ridges, coastal cliffs, snow patches and ice wedges are part of the GeoBasis monitoring.

Solifluction

In 1992, two monitoring sites were established in order to register the rate of solifluction. One site was located on the western side of Ulvehøj (SF-1) and the other site (SF-2) was established south of the station near the old delta. At SF-1, ten pegs were installed parallel to the direction of flow in a profile starting in front of the solifluction lobe front with a total length of 548.3 cm in 1992. In 2006, when the distance between the pegs were re-measured the total length was reduced to 519.1 cm and the peg right in front of the lobe had been overridden. At the lobe front the distance between pegs were reduced and an average forward movement of 1.25 cm/year was found, whereas the distance between the pegs in the other end of the profile had increased by 0.22 cm/year. At SF-2, pegs were installed in a profile perpendicular to the flow direction and no changes were registered at the re-measurement in 2006.

Table 2.14 Cumulated coastal cliff recession at the southern coast of Zackenbergdalen 1996-2006.

	Recession (m)			
	Site 1	Site 2	Site 3	Site 4
1996-1997	0	0	0.3	1
1996-1998	0	0	0.3	1.3
1996-1999	0	0	0.3	1.3
1996-2000	0	0	0.5	1.4
1996-2001	0	0	0.5	1.4
1996-2002	0	0	0.7	2.8
1996-2003	0	0.4	1.6	3.2
1996-2004	0	0.5	1.7	3.2
1996-2005	0	0.7	1.7	3.2
1996-2006	0	0.9	1.8	3.2

Coastal geomorphology

Cliff recession along the southern coast of Zackenbergdalen is measured every year in August. From 2005 to 2006 only minor erosion took place at site 2 (20 cm) and site 3 (10 cm) Table 2.14.

In the Zackenberg river delta rapid erosion is observed along the delta cliff on the western side of the river due to fluvial thermo erosion and subsequent block slumping. The cliff is 8-12 m high and especially along the outer 200 m of the cliff, dramatic recession rates of up to 10 m/yr, has been observed. On average, a total retreat of 30-40 m has taken place during the last 10 years and today the outer part of the cliff is only 5-10 m wide.

In 2006, the topographic cross shore profiles near the old delta were re-surveyed in August. Only minor topographic changes had occurred since last measurement in 2004.

3 ZACKENBERG BASIC
The BioBasis programme

Niels Martin Schmidt (ed.)

The BioBasis programme at Zackenberg is carried out by the National Environmental Research Institute (NERI), Department of Arctic Environment, Aarhus University, Denmark. It is funded by the Danish Environmental Protection Agency as part of the environmental support program Dancea – Danish Cooperation for Environment in the Arctic. The authors are solely responsible for all results and conclusions presented in the report, which do not necessarily reflect the position of the Danish Environmental Protection Agency.

Details on BioBasis methods and sampling protocols are available at the home page of NERI (http://biobasis.dmu.dk).

3.1 Vegetation

Jannik Hansen and Niels Martin Schmidt

The weekly records of snow-cover, plant flowering and reproduction were conducted by Martin Ulrich Christensen during 26 May – 27 August. He was assisted by Niels Martin Schmidt, Ditte K. Hendrichsen and Jannik Hansen at different times during the season.

Reproductive phenology, amounts of flowering and berry production

The field season began on 27 May. Compared to previous years, 2006 had late

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Cassiope 1	14.6	9.6	13.6	27.6	2.6	7.6	13.6	6.6	<3.6	23.5	13.6
Cassiope 2	19.6	21.6	27.6	4.7	<4.6	21.6	20.6	13.6	16.6	7.6	2.7
Cassiope 3	15.6	21.6	20.6	3.7	13.6	20.6	20.6	7.6	7.6	28.5	28.6
Cassiope 4	20.6	15.6	20.6	4.7	13.6	21.6	17.6	7.6	7.6	7.6	23.6
Dryas 1	<3.6	<27.5	(23.5)	6.6	<4.6	<31.5	<30.5	4.6	<2.6	<20.5	30.5
Dryas 2	26.6	27.6	4.7	12.7	21.6	3.7	28.6	22.6	21.6	17.6	11.7
Dryas 3	6.6	<27.5	7.6	19.6	<4.6	6.6	6.6	6.6	<3.6	<20.5	31.5
Dryas 4	1.6	3.6	13.6	21.6	<4.6	7.6	6.6	(31.5)	<1.6	(28.4)	13.6
Dryas 5	6.6	31.5	4.6	14.6	<4.6	5.6	6.6	6.6	<1.6	<20.5	26.6
Dryas 6	21.6	4.7	5.7	11.7	20.6	28.6	30.6	19.6	21.6	14.6	10.7
Papaver 1	20.6	18.6	21.6	3.7	1.6	20.6	18.6	12.6	14.6	1.6	28.6
Papaver 2	20.6	20.6	21.6	4.7	14.6	21.6	20.6	21.6	11.6	7.6	2.7
Papaver 3	21.6	15.6	20.6	3.7	13.6	21.6	19.6	14.6	8.6	7.6	23.6
Papaver 4	21.6	4.7	5.7	11.7	20.6	27.6	30.6	19.6	21.6	12.6	10.7
Salix 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5	(31.5)	<3.6	<20.5	(25.5)
Salix 2	14.6	20.6	23.6	1.7	13.6	21.6	14.6	14.6	9.6	5.6	27.6
Salix 3	7.6	8.6	12.6	24.6	<3.6	7.6	7.6	(2.6)	<3.6	(18.5)	9.6
Salix 4	20.6	5.6	21.6	22.6	7.6	11.6	10.6	13.6	5.6	30.5	14.6
Salix 5	-	-	-	-	-	-	-	21.6	11.6	7.6	2.7
Salix 6	-	-	-	-	-	-	-	-	21.6	15.6	5.7
Salix 7	-	-	-	-	-	-	-	-	21.6	15.6	11.7
Saxifraga 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5	(1.6)	<2.6	<20.5	<26.5
Saxifraga 2	<3.6	<27.5	<27.5	(27.5)	<3.6	<31.5	<30.5	(31.5)	<2.6	<20.5	<26.5
Saxifraga 3	-	<27.5	27.5	6.6	<3.6	(27.5)	<30.5	(1.6)	<2.6	(8.5)	7.6
Silene 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5	(1.6)	<2.6	<20.5	<26.5
Silene 2	<3.6	<27.5	<27.5	(27.5)	<3.6	<31.5	<30.5	(31.5)	<2.6	<20.5	<26.5
Silene 3	-	<27.5	27.5	6.6	<3.6	(27.5)	<30.5	(1.6)	<2.6	(8.5)	7.6
Silene 4	24.6	28.6	20.6	6.7	21.6	28.6	25.6	19.6	18.6	12.6	5.7

Table 3.1. Inter- and extrapolated dates of 50% snow-cover for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *plots 1996-2006. Brackets denote extrapolated dates.*

Table 3.2. Inter- and extrapolated dates of 50% open flowers (50/50 ratio of buds/open flowers) for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *1996-2006. Brackets denote interpolated dates based on less than 50 buds+flowers.*

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Cassiope 1	2.7	6.7	6.7	13.7	(28.6)	4.7	3.7	27.6	23.6	16.6	4.7
Cassiope 2	6.7	20.7	(21.7)	(26.7)	-	12.7	7.7	3.7	5.7	22.6	20.7
Cassiope 3	9.7	18.7	(19.7)	(26.7)	-	11.7	9.7	2.7	30.6	22.6	19.7
Cassiope 4	15.7	15.7	(21.7)	(26.7)	-	19.7	7.7	5.7	3.7	2.7	19.7
Dryas 1	19.6	22.6	26.6	3.7	26.6	22.6	25.6	30.6	21.6	13.6	26.6
Dryas 2	13.7	4.8	8.8	-	24.7	1.8	29.7	19.7	18.7	17.7	3.8
Dryas 3	2.7	26.6	6.7	13.7	27.6	6.7	28.6	29.6	23.6	13.6	29.6
Dryas 4	27.6	6.7	(9.7)	14.7	26.6	6.7	28.6	23.6	22.6	13.6	6.7
Dryas 5	30.6	5.7	1.7	7.7	22.6	5.7	28.6	28.6	20.6	13.6	21.6
Dryas 6	19.7	9.8	(7.8)	19.8	21.7	29.7	1.8	17.7	17.7	13.7	2.8
Papaver 1	14.7	20.7	24.7	2.8	4.7	12.7	12.7	5.7	11.7	4.7	25.7
Papaver 2	14.7	23.7	26.7	30.7	15.7	14.7	13.7	8.7	8.7	9.7	27.7
Papaver 3	14.7	19.7	26.7	1.8	10.7	17.7	13.7	11.7	5.7	6.7	20.7
Papaver 4	15.7	7.8	11.8	15.8	(20.7)	(27.7)	2.8	17.7	12.7	13.7	2.8
Salix 1	6.6	6.6	12.6	14.6	11.6	8.6	9.6	17.6	4.6	4.6	14.6
Salix 2	21.6	29.6	10.7	17.7	28.6	29.6	28.6	28.6	21.6	14.6	15.7
Salix 3	20.6	25.6	(28.6)	5.7	11.6	24.6	16.6	15.6	7.6	6.6	23.6
Salix 4	29.6	23.6	2.7	3.7	17.6	28.6	26.6	23.6	21.6	13.6	29.6
Salix 5	-	-	-	-	-	-	-	5.7	23.6	13.6	13.7
Salix 6	-	-	-	-	-	-	-	-	15.7	3.7	19.7
Salix 7	-	-	-	-	-	-	-	-	5.7	6.7	21.7
Saxifraga 1	-	31.5	5.6	7.6	6.6	8.6	3.6	14.6	5.6	24.5	(31.5)
Saxifraga 2	-	2.6	7.6	14.6	9.6	8.6	6.6	14.6	5.6	1.6	6.6
Saxifraga 3	5.6	1.6	9.6	16.6	7.6	9.6	7.6	14.6	<2.6	26.5	21.6
Silene 1	20.6	24.6	21.6	28.6	26.6	28.6	23.6	1.7	21.6	14.6	19.6
Silene 2	23.6	29.6	1.7	30.6	2.7	30.6	27.6	4.7	29.6	15.6	1.7
Silene 3	30.6	26.6	23.6	6.7	28.6	4.7	28.6	4.7	20.6	15.6	13.7
Silene 4	26.7	10.8	20.8	-	28.7	29.7	28.7	20.7	19.7	16.7	13.7

snowmelt. On 10 June, snow cover in the valley was extensive in the 13 sub-zones in which snow cover is being estimated (see section 2.2). The exact snow cover percentage has not yet been calculated due to ongoing calibration of software (see section 2.2).

Dates of 50% snow-cover in 9 of 28 plant plots were the latest recorded so far, 8 were the 2nd latest ever recorded and 5 later than usual (Table 3.1).

The late snowmelt also resulted in the latest flowering recorded during the 11 years of monitoring for 5 of 28 plant plots; a further 19 were later than usual. Flowering in the remaining four plots had flowering dates close to average, while two plots had earlier than usual flowering (Table 3.2).

The short growing season (see Table 2.13) was also reflected in the dates of 50% open seed capsules. For the three species monitored, arctic poppy *Papaver radicatum*, arctic willow *Salix arctica* and purple saxifrage *Saxifraga oppositifolia*, dates were among the latest observed so far (Table 3.3). Similarly, the short growing season

Table 3.3. Inter- and extrapolated dates of 50% open seed capsules for arctic poppy Papaver radicatum, *arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia *1995-2006. Brackets denote interpolated dates based on less than 50 flowers+open capsules.*

Plot	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Papaver 1	5.8	15.8	-	30.8	>26.8	9.8	16.8	20.8	1.8	6.8	31.7	20.8
Papaver 2	15.8	15.8	24.8	-	>26.8	(17.8)	16.8	17.8	3.8	6.8	3.8	22.8
Papaver 3	6.8	13.8	19.8	-	29.8	14.8	18.8	20.8	6.8	3.8	31.7	11.8
Papaver 4	20.8	-	>27.8	-	(>26.8)	(16.8)	24.8	(26.8)	10.8	14.8	8.8	(27.8)
Salix 1	8.8	8.8	8.8	5.8	13.8	12.8	2.8	29.7	2.8	26.7	20.7	7.8
Salix 2	12.8	9.8	19.8	30.8	25.8	20.8	18.8	11.8	3.8	5.8	3.8	19.8
Salix 3	2.8	8.8	16.8	(19.8)	16.8	12.8	14.8	5.8	28.7	27.7	25.7	11.8
Salix 4	12.8	17.8	14.8	21.8	16.8	13.8	13.8	12.8	3.8	6.8	29.7	11.8
Salix 5	-	-	-	-	-	-	-	-	4.8	7.8	7.8	>28.8
Salix 6	-	-	-	-	-	-	-	-	11.8	10.8	14.8	>28.8
Salix 7	-	-	-	-	-	-	-	-	13.8	10.8	14.8	>28.8
Saxifraga 1	-	20.7	10.8	11.8	13.8	9.8	8.8	4.8	7.8	23.7	22.7	(5.8)
Saxifraga 2	-	23.7	16.8	24.8	15.8	15.8	14.8	1.8	11.8	27.7	31.7	5.8

Plot	Area	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean	2006
Cassiope 1	2	1321	1386	1855	322	312	28	1711	1510	851	2080	1392	1160,7	973
Cassiope 2	3		1759	550	19	16	8	1353	952	1001	1745	1203	860,6	593
Cassiope 3	2	256	844	789	35	18	0	771	449	817	791	862	512,0	432
Cassiope 4	3	456	1789	391	24	6	3	578	164	1189	1274	1857	702,8	520
Cassiope 5	2.5	-	-	1224	455	474	50	3214	3208	2708	2006	2648	1776,3	1238
Cassiope 6	2	-	-	>350	16	3	1	544	736	134	2796	3938	1021,0	610
Dryas 1	4	936	797	138	223	852	607	1016	627	744	444	391	615,9	321
Dryas 2	60	534	1073	230	42	49	46	172	290	552	1174	519	425,5	521
Dryas 3	2	603	522	123	255	437	266	577	235	294	273	198	343,9	134
Dryas 4	6	325	164	155	69	356	55	301	187	224	218	143	199,7	168
Dryas 5	6	654	504	123	191	655	312	506	268	589	351	233	398,7	123
Dryas 6	91	809	1406	691	10	25	140	550	430	627	1854	878	674,5	1324
Dryas 7	12	-	-	787	581	1355	574	1340	1483	1543	1026	599	1032,0	363
Dryas 8	12	-	-	391	240	798	170	403	486	545	229	243	389,4	119
Papaver 1	105	302	337	265	190	220	197	237	277	278	286	207	254,2	153
Papaver 2	150	814	545	848	316	315	236	466	456	564	402	682	513,1	416
Papaver 3	90	334	238	289	266	183	240	259	301	351	221	316	272,5	234
Papaver 4	91	196	169	192	80	30	35	65	59	56	37	68	89,7	71
Salix 1 mm.	60	-	807	959	63	954	681	536	1454	1931	1127	375	888,7	303
Salix 1 ff.	-	520	1096	1349	149	1207	900	1047	1498	2159	1606	386	1083,4	223
Salix 2 mm.	300	-	790	1082	132	416	55	803	1206	967	1276	737	746,4	654
Salix 2 ff.	-	617	1376	1909	455	418	95	1304	1816	1638	1862	1089	1143,5	1076
Salix 3 mm.	36	239	479	412	32	52	330	1196	344	621	693	285	425,7	204
Salix 3 ff.	-	253	268	237	38	68	137	1009	315	333	476	188	302,0	129
Salix 4 mm.	150	-	1314	831	509	718	965	680	1589	1751	1984	1317	1165,8	1508
Salix 4 ff.		1073	1145	642	709	880	796	858	1308	1418	1755	1038	1056,5	905
Salix 5 mm.	-	-	-	-	-	-	-	-	-	494	844	945	761,0	1052
Salix 5 ff.	-	-	-	-	-	-	-	-	-	371	1314	1333	1006,0	1365
Salix 6 mm.	-	-	-	-	-	-	-	-	-	-	2162	2445	2303,5	591
Salix 6 ff.	-	-	-	-	-	-	-	-	-	1145	2736	2010	1963,7	947
Salix 7 mm.	-	-	-	-	-	-	-	-	-	612	621	746	659,7	286
Salix 7 ff.	-	-	-	-	-	-	-	-	-	839	512	705	685,3	180
Saxifraga 1	7	-	1010	141	163	584	1552	558	542	1213	463	159	638,5	36
Saxifraga 2	6	-	513	387	432	158	387	515	617	561	584	522	467,6	167
Saxifraga 3	10	-	529	322	288	707	403	558	318	509	609	241	448,4	150
Silene 1	7	-	251	403	437	993	1327	674	766	1191	1187	312	754,1	430,00
Silene 2	6	-	493	524	440	400	692	568	1094	917	1406	740	727,4	540,00
Silene 3	10	-	348	211	127	313	274	348	480	1000	719	503	432,3	739,00
Silene 4	1	466	270	493	312	275	358	462	470	794	509	483	444,7	312,00
E. scheuz. 1	10	-	395	423	257	309	229	111	582	843	780	201	413,0	302
E. scheuz. 2	6	-	537	344	172	184	201	358	581	339	956	597	426,9	540
E. scheuz. 3	10	-	392	545	482	587	38	367	260	237	359	67	333,4	44
E. scheuz. 4	8	-	260	755	179	515	117	121	590	445	176	57	321,5	23
E. triste 1	10	-	0	3	1	1	1	0	3	11	12	0	3,2	0
E. triste 2	6	-	98	59	21	16	43	56	67	39	117	44	56,0	49
E. triste 3	10	-	0	0	0	0	0	0	0	0	0	0	0,0	0
E. triste 4	8	-	0	0	0	0	0	0	0	0	0	0	0,0	0
Arctostaphylos 1	-	-	-	-	-	-	-	-	1865	3035	285	1775	1740,0	2920
Arctostaphylos 2	-	-	-	-	-	-	-	-	215	272	>10	103	196,7	253
Arctostaphylos 3	-	-	-	-	-	-	-	-	387	375	>68	291	351,0	423
Arctostaphylos 4	-	-	-	-	-	-	-	-	996	1216	563	1197	993,0	1136
Vaccinium 1	-	-	-	-	-	-	-	-	2521	9271	6067	6571	6107,5	4506

Table 3.4. Area size (m²) and pooled numbers of flower buds, flowers and senescent flowers of white arctic bell-heather Cassiope tetragona, mountain avens Dryas integrifolia/octopetala*, arctic poppy* Papaver radicatum*, arctic willow* Salix arctica*, purple saxifrage* Saxifraga oppositifolia*, moss campion* Silene acaulis*, arctic cotton-grass* Eriophorum scheuzerii*, 'dark cotton-grass'* Eriophorum triste*, alpine bearberry* Arctostaphylos alpina*, and Arctic blueberry* Vaccinium uliginosum *in flower plots in 1995-2006. Numbers in brackets have been extrapolated from 1995 and 1996 data to adjust for enlargement of plots (see Meltofte and Rasch 1998).*

Table 3.5. Peak ratio (per cent) of female Salix pods infested by fungi in Salix plots in 1996-2006.

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Salix 1	5	4	0	22	4	1	3	+	2	0	0
Salix 2	0	1	2	2	0	0	1	0	0	1	0
Salix 3	0	0	0	6	0	0	2	0	0	0	0
Salix 4	16	3	0	6	0	0	0	0	3	0	0
Salix 5	-	-	-	-	-	-	-	-	3	4	0
Salix 6	-	-	-	-	-	-	-	-	0	0	0
Salix 7	-	-	-	-	-	-	-	-	0	1	0

Table 3.6. Area size (m^2) and numbers of berries recorded in alpine bearberry Arctostaphylos alpina, Arctic blueberry Vaccinium uliginosum and crowberry Empetrum nigrum plots in 1998-2006.

Species	Area	1998	1999	2000	2001	2002	2003	2004	2005	2006
Arctostaphylos 1	1.5	148	240	30	99	33	122	22	53	403
Arctostaphylos 2	1.5	50	17	2	36	18	55	1	1	43
Arctostaphylos 3	1.5	28	91	4	100	32	21	16	16	70
Arctostaphylos 4	1.5	139	107	0	14	44	106	201	187	149
Vaccinium 1	4	240	532	9	0	1	14	3	15	5
Empetrum 1	4	27	1	17	3081	1034	4568	1084	1955	2215

also resulted in a generally low numbers of flowers produced (Table 3.4). More than 70% of all plots produced fewer flowers than the 1996-2005 average. More flowers than average were only produced in 13 of the 52 plots, mainly in Arctic willow plots, alpine bearberry (*Arctostaphylos alpina*) plots and mountain avens (*Dryas sp.*) plots.

No arctic willow catkins were found infested with fungi in any plot in 2006 (Table 3.5). This contrast the previous season with very low snow melt (1999), where the highest infestation rate was observed, probably caused by the late snow melt and normal precipitation.

In 2006 berry production was fairly high – in fact, the highest or third highest for all alpine bearberry plots (*Arctostaphylos alpina*), and third highest for crow berry (*Empetrum nigrum*), potentially due to high ground moisture following the thick snow cover. Only Arctic blueberry (*Vaccinium uliginosum*) had very low production (Table 3.6).

Table 3.7. Area size (km^2) and Normalised Difference Vegetation Index (NDVI) values for 13 sections of the bird and musk ox monitoring areas in Zackenbergdalen together with the lemming monitoring area based on an ASTER satellite image from 2 August 2006 (see Fig. 4.1 in Caning and Rasch (2003) for position of sections). The image has been corrected for atmospheric and terrain influence (humidity, aerosols, solar angle and terrain effects). All negative NDVI values, i.e. from water and snow-covered areas, have been replaced by zeros.

Section	Area	Min.	Max.	Mean	Std.Dev.
1 (0-50 m)	3.52	0.00	0.75	0.39	0.24
2 (0-50 m)	7.97	0.00	1.00	0.47	0.26
3 (50-150 m)	3.52	0.00	0.81	0.48	0.24
4 (150-300 m)	2.62	0.00	0.73	0.38	0.22
5 (300-600 m)	2.17	0.00	0.73	0.28	0.19
6 (50-150 m)	2.15	0.00	0.70	0.43	0.24
7 (150-300 m)	3.36	0.00	0.74	0.40	0.23
8 (300-600 m)	4.56	0.00	0.81	0.32	0.23
9 (0-50 m)	5.01	0.00	0.77	0.47	0.24
10 (50-150 m)	3.84	0.00	0.75	0.49	0.24
11 (150-300 m)	3.18	0.00	0.76	0.39	0.24
12 (300-600 m)	3.82	0.00	0.83	0.39	0.25
13 (Lemmings)	2.05	0.00	0.71	0.45	0.25
Total Area	**45.72**	**0.00**	**0.78**	**0.42**	**0.24**

Vegetation greening in mammal, bird and flower study plots

The greening index data (NDVI) from an ASTER satellite image from 2 August 2006 are presented in Table 3.7. Means for 2006 are compared with data from previous years after extrapolation to simulate 31 July each year (Table 3.8). See Fig. 4.1 in Caning and Rasch (2003) for location of sections in Zackenbergdalen. Despite the late melting of the snow, landscape NDVI in all sections was around the average of the previous years (Table 3.8). In the 26 plant plots, the greening of the vegetation (NDVI) culminated relatively late in the season when compared to the previous years, but generally not as late as the last snow-rich year 1999. Also, in contrast to 2005 (see Klitgaard et al. 2006), NDVI peaked in a single peak in 2006, and with an overall low mean value (Table 3.9).

3.2 Arthropods

Jannik Hansen and Niels Martin Schmidt

Five pitfall trap stations, each with eight subplots (yellow trap cups), and one window trap station, with two traps, were open during the 2006 season. Sampling procedures were concurrent with previous seasons. Field work was carried out by Martin U. Christensen. Niels M. Schmidt contributed to the field collections. Samples were sorted by personnel from the Department of Terrestrial Ecology at the National Environmental Research Institute, Silkeborg, Denmark. The material is stored in 70% ethanol at the Museum of Natural History, Aarhus, and is avail-

Section	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1 (0-50 m)	0.37	0.43	0.44	0.44	0.30	0.41	0.34	0.34	-	0.42	0.34	0.39
2 (0-50 m)	0.43	0.50	0.50	0.51	0.41	0.48	0.43	0.44	-	0.50	0.39	0.47
3 (50-150 m)	0.54	0.53	0.54	0.53	0.41	0.51	0.47	0.49	-	0.54	0.44	0.48
4 (150-300 m)	0.46	0.45	0.46	0.44	0.31	0.43	0.36	0.38	-	0.41	0.35	0.38
5 (300-600 m)	0.36	0.35	0.38	0.38	0.22	0.37	0.26	0.26	-	0.31	0.26	0.28
6 (50-150 m)	0.48	0.48	0.47	0.46	0.33	0.44	0.39	0.41	-	0.46	0.39	0.43
7 (150-300 m)	0.48	0.46	0.48	0.45	0.32	0.43	0.38	0.39	-	0.45	0.37	0.40
8 (300-600 m)	0.42	0.38	0.41	0.42	0.25	0.35	0.28	0.29	-	0.33	0.29	0.32
9 (0-50 m)	0.42	0.50	0.52	0.51	0.39	0.50	0.44	0.45	-	0.52	0.40	0.47
10 (50-150 m)	0.52	0.53	0.54	0.52	0.40	0.52	0.48	0.48	-	0.55	0.44	0.49
11 (150-300 m)	0.47	0.45	0.46	0.42	0.26	0.41	0.35	0.36	-	0.45	0.36	0.39
12 (300-600 m)	0.42	0.42	0.44	0.45	0.28	0.32	0.34	0.33	-	0.41	0.35	0.39
13 (Lemmings)	0.42	0.49	0.50	0.49	0.40	0.47	0.41	0.43	-	0.48	0.38	0.45
Total	**0.45**	**0.46**	**0.48**	**0.47**	**0.32**	**0.43**	**0.38**	**0.38**	**-**	**0.45**	**0.37**	**0.42**

Table 3.8. Mean NDVI values for 13 sections of the bird and musk ox monitoring areas in Zackenbergdalen together with the lemming monitoring area based on Landsat TM, ETM+ and SPOT 4 HRV and ASTER satellite images 1998-2006 (see Fig. 4.1 in Caning and Rasch (2003) for position of sections). The data have been corrected for differences in growth phenology between years to simulate the 31 July value, i.e. the approximate optimum date for the plant communities in most years. Note that the 2005 values have been recalculated (see Table 3.8 in Klitgaard et al. 2006).

able for further study. Please contact the BioBasis manager concerning access to the collection.

Ice and snow at the stations generally melted late (Table 3.10), and especially station 3 and 4 melted very late compared to previous seasons.

The total number of arthropods collected in 2006 was well above 31,703. The total number is currently underestimated, as a number of samples have not been fully sorted for a few, but very numerous groups, namely springtails (Collembola), mites and ticks (Acarina).

Window traps

This year the first window trap (facing north-south) in Gadekæret was opened on 27 May, when both ponds were still fully covered with ice and snow. The second trap (east-west) was opened on 30 May, when the western pond was still 90% ice covered. The traps worked continuously until 26 August. The total number of specimens caught this season in the window traps was 10,216 (Table 3.11). This number is at the high end of the range for 1996-2006. Only in 2000, more specimens were caught (10,588). Like previous years, midges (chironomids) constituted the bulk of specimens caught (Table 3.11). This year the chironomids had a very distinct peak one week later than average for the years 1996-2005 (Fig. 3.1), probably due to the generally extensive snow cover and late ice melt on the pond around the traps (Table 3.10).

Dark-winged fungus gnats (Sciaridae) and leaf miner flies (Agromyzidae) were caught at a near normal level this year, leaving last year's high number as a lone peak in numbers of 1996-2006 (Table 3.11). Mosquitoes (Culicidae) were caught at the lowest numbers yet, whereas dung flies (Anthomyidae), midges (Chironomidae) and wolf spiders (Lycosidae) were caught at the highest number in window traps since the beginning of the programme (Table 3.11).

Two blues (Lycaenidae) was caught in the north facing window trap on 5 August, and another on 12 August. This is only the third season Lycaenidae have been caught

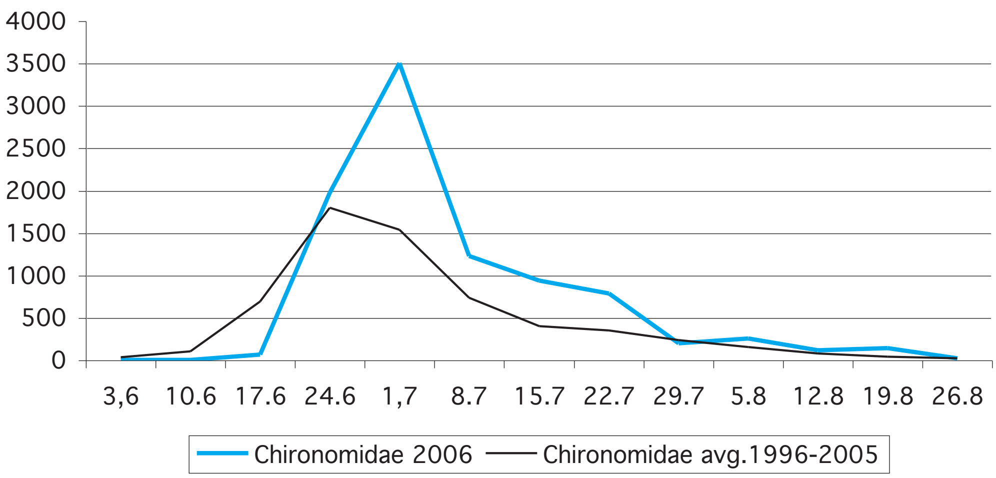


Fig. 3.1. Numbers of chironomid midges Chironomidae caught per week in the window traps 2006 compared with the mean for 1996-2005.

Plot	1999		2000		2001		2002		2003		2005 early		2005 late		2006	
	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date
Cassiope 1	0.40	29.7	0.41	29.7	0.37	5.8	0.35	29.7	0.36	5.8	0.34	9.7	0.30	22.7	0.28	22.7
Cassiope 2	0.41	29.7	0.46	22.7	0.38	22.7	0.38	26.8	0.43	5.8	0.37	9.7	0.39	22.7	0.38	27.8
Cassiope 3	0.41	19.8	0.36	19.8	0.33	5.8	0.31	26.8	0.34	12.8	0.30	9.7	0.34	29.7	0.34	12.8
Cassiope 4	0.38	26.8	0.41	22.7	0.35	29.7	0.33	26.8	0.39	5.8	0.34	9.7	0.39	29.7	0.38	31.7
Mean	0.40		0.41		0.36		0.34		0.38		0.34		0.36		0.35	
Dryas 1	0.43	22.7	0.41	22.7	0.37	22.7	0.35	25.7	0.40	22.7	0.32	9.7	0.25	29.7	0.26	22.7
Dryas 2/Salix 7	0.39	19.8	0.42	22.7	0.39	29.7	0.43	5.8	0.42	5.8	0.36	9.7	0.37	22.7	0.36	27.8
Dryas 3	0.45	29.7	0.45	22.7	0.42	26.7	0.41	29.7	0.46	22.7	0.33	9.7	0.31	29.7	0.33	31.7
Dryas 4	0.34	19.8	0.32	22.7	0.33	22.7	0.28	29.7	0.29	22.7	0.25	9.7	0.29	29.7	0.30	31.7
Dryas 5	0.34	29.7	0.33	22.7	0.31	22.7	0.28	29.7	0.31	15.7	0.20	9.7	0.23	29.7	0.21	31.7
Dryas 6/Papaver 4	0.35	26.8	0.41	22.7	0.34	26.7	0.37	5.8	0.38	22.7	0.33	9.7	0.36	29.7	0.36	12.8
Mean	0.38		0.39		0.36		0.35		0.38		0.30		0.30		0.30	
Papaver 1	0.41	19.8	0.41	22.7	0.38	29.7	0.39	29.7	0.41	22.7	0.35	9.7	0.37	22.9	0.36	31.7
Papaver 2/Salix 5	0.44	19.8	0.45	22.7	0.41	29.7	0.40	5.8	0.42	29.7	0.37	9.7	0.43	29.7	0.40	31.7
Papaver 3	0.37	26.8	0.41	22.7	0.35	29.7	0.34	5.8	0.39	22.7	0.33	9.7	0.39	29.7	0.38	31.7
Mean	0.39		0.42		0.37		0.37		0.40		0.35		0.39		0.38	
Salix 1	0.57	29.7	0.59	22.7	0.54	8.7	0.54	22.7	0.60	15.7	0.51	9.7	0.43	29.7	0.48	22.7
Salix 2	0.52	29.7	0.52	22.7	0.49	29.7	0.51	22.7	0.50	22.7	0.46	9.7	0.42	29.7	0.46	8.8
Salix 3	0.41	29.7	0.44	22.7	0.39	29.7	0.38	29.7	0.38	22.7	0.34	9.7	0.31	22.7	0.32	22.7
Salix 4	0.46	29.7	0.47	22.7	0.43	2.8	0.45	29.7	0.47	15.7	0.40	9.7	0.38	29.7	0.42	31.7
Salix 6	-	-	-	-	-	-	-	-	0.39	31.7	0.33	9.7	0.43	29.7	0.45	31.7
Mean	0.46		0.48		0.44		0.45		0.46		0.40		0.40		0.43	
Saxifraga/Silene 1	0.28	29.7	0.34	7.8	0.27	8.7	0.19	22.7	0.27	15.7	0.19	9.7	0.15	29.7	0.19	31.7
Saxifraga/Silene 2	0.36	29.7	0.38	22.7	0.34	19.7	0.31	22.7	0.38	15.7	0.34	9.7	0.27	15.7	0.28	31.7
Saxifraga/Silene 3	0.23	29.7	0.26	22.7	0.27	15.7	0.20	29.7	0.24	22.7	0.17	9.7	0.15	29.7	0.20	31.7
Silene 4	0.32	26.8	0.36	22.7	0.27	29.7	0.26	5.8	0.28	29.7	0.26	9.7	0.30	29.7	0.28	12.8
Mean	0.30		0.34		0.29		0.24		0.29		0.24		0.22		0.24	
Eriophorum 1	0.57	5.8	0.60	14.7	0.60	29.7	0.57	29.7	0.61	15.7	-	-	0.54	15.7	0.55	8.8
Eriophorum 2	0.58	29.7	0.58	22.7	0.53	26.7	0.50	29.7	0.45	15.7	0.44	9.7	0.44	15.7	0.44	8.8
Eriophorum 3	0.54	19.8	0.56	22.7	0.47	29.7	0.47	29.7	0.48	22.7	0.37	9.7	0.35	22.7	0.39	12.8
Eriophorum 4	0.73	5.8	0.72	22.7	0.68	29.7	0.64	5.8	0.67	22.7	-	-	0.70	29.7	0.69	8.8
Mean	0.61		0.62		0.57		0.54		0.55		0.41		0.51		0.52	
Mean of all	0.43		0.44		0.40		0.39		0.41		0.33		0.36		0.37	

Table 3.9. Peak NDVI recorded in 26 plant plots 1999-2006 together with date of maximum values. NDVI values presented are transformed RVI averages of eight (four in very small plots) hand held measurements in each plot. Note that the greening measured accounts for the entire plant community, in which the taxon denoted may only make up a smaller part. Data from 2004 are not included due to instrumental error that season.

at Zackenberg, previously being caught in pitfall traps in 2000 and 1999 (Table 3.12; Caning and Rasch 2000, 2001). However, although only caught in window traps this season, Lycaenidae are observed most years and not uncommon to the area. See Pitfall traps for more catches of Lycaenidae.

Pitfall traps

The first pitfall traps were established on 27 May, and all traps were in use from 4 July and until 26 August. Due to damage by musk oxen, one trap was replaced during the season. The number of trapping days in 2006 was 2979, which is in the lower half compared to previous seasons, and due to a late thaw at most trap stations (Table 3.10). Weekly totals were pooled for all five stations and presented in Table 3.12 with totals from 2003-2005 for comparison. In the 2006 season in the excess of 21,487 arthropods were collected from the pitfall traps. This number is low compared to other years, which also reflects the low numbers of Acarina and Collombola groups that have not yet been fully sorted for several sub plots (marked by '#' in Table 3.12). The total number, and the number of

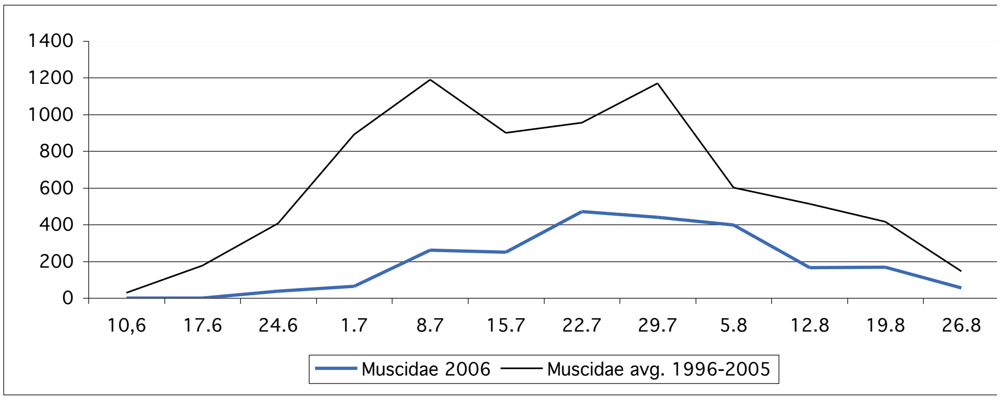


Fig. 3.2. Numbers of houseflies Muscidae caught per week in the pitfall traps in 2006 compared with means 1996-2005.

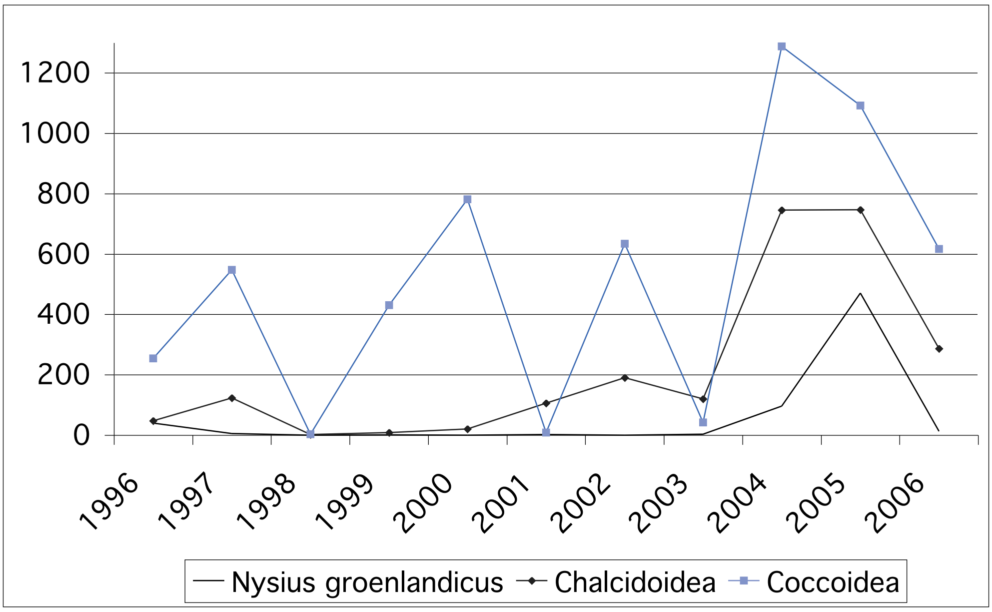


Fig. 3.3. Numbers of Coccoidea, Chalcidoidea and Nysius groenlandicus *caught during 1996-2006.*

Acarina and Collembola, is thus likely to be much higher.

A number of small sized groups were collected in record high numbers; the seed shrimps (Ostracoda), roundworms (Nematoda) and potworms (Enchytraeidae). The numbers are much higher than ever before, which is mainly due to more sophisticated equipment for sorting. The aphids (Aphiodoidea) were collected in the lowest numbers since 2000, whereas the Lepidoptera larvae were found in the second highest numbers since 1997. The butterfly hecla sulphur (*Colias hecla*) was missing completely, which has happened only once before, in 2001. As mentioned above a rare window trap catch of a butterfly belonging to the Lycaenidae was accompanied by a record high number of Lycaenidae catches in pitfall traps (Table. 3.12).

Chironomidae were caught in high numbers – the 4th highest number since the beginning of the programme. Also, Sciaridae were caught in higher numbers than ever before. Hoverflies (Syrphidae) were caught in much lower numbers than usual, and house flies (Muscidae) were found in the lowest numbers yet. Also, the peaks in house fly numbers were lower and less distinct than in previous years (Fig 3.2).

The seed bug *Nysius groenlandicus* were

Station no.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Art. 1	3.6	Dry	6.6	16.6	1.6	6.6	3.6	12.6	<1.6**	<20.5	5.6
Art. 2	<3.6*	28.5	29.5	8.6	<4.6*	<31.5*	<31.5*	1.6	<1.6*	<20.5*	<27.5
Art. 3	14.6	19.6	18.6	27.6	9.6	19.6	14.6	20.6	4.6	3.6	23.6
Art. 4	14.6	22.6	26.6	2.7	7.6	21.6	20.6	11.6	6.6	4.6	28.6
Art. 5	4.6	<29.5*	1.6	12.6	<4.6*	8.6	3.6	5.6	<1.6*	<20.5	3.6
Art. 7	-	-	-	<3.6	<4.6*	<30.5	<31.5*	2.6	<1.6*	<20.5	<27.5

Table 3.10. Date of 50% snow-cover (ice-cover on pond at Station 1) in the arthropod plots 1996-2006.

** 0% snow*
*** 7% ice cover*

Date	3.6	10.6	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	18.8	26.8	2006	2005	2004	2003	2002	2001	2000	1999
No. of trap days	**11**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**12**	**15**	**178**	**195**	**172**	**168**	**168**	**168**	**166**	**153**
COLLEMBOLA			10	7	8	#	#	#	6	#	4		0	**35**	112	175	31	191	119	102	61
COLEOPTERA																					
Latridius minutus														**0**	0	0	0	0	0	0	2
HEMIPTERA																					
Nysius groenlandicus									1					**1**	6	10	0	1	0	0	0
Aphidoidea														**0**	8	3	1	0	2	0	0
Coccoidea														**0**	0	0	0	0	0	3	0
THYSANOPTERA			3						2	1	1			**7**	7	11	0	3	1	0	0
LEPIDOPTERA																					
Colias hecla														**0**	1	9	2	6	0	2	0
Clossiana sp.									1		1	1		**3**	1	5	4	1	1	2	1
Lycaenidae										2	1			**3**	0	0	0	0	0	0	0
Geometridae														**0**	0	0	0	2	3	0	0
Noctuidae										3			1	**4**	7	1	1	0	0	0	0
DIPTERA																					
Nematocera larvae														**0**	0	0	0	2	0	0	1
Nematocera undet.														**0**	0	0	0	0	1418	0	0
Tipulidae														**0**	0	0	1	0	0	0	1
Trichoceridae														**0**	0	2	0	0	0	0	0
Culicidae						7	20	7	7	6	8	10	3	**68**	128	104	96	232	209	111	322
Chironomidae	8	6	70	1977	3505	1234	943	793	203	261	120	145	25	**9290**	6470	5203	7792	6378	3876	8522	5787
Ceratopogonidae				7	5	4	2	3	1	3	1	4	2	**32**	9	21	66	1598	168	*	1799
Mycetophiliidae							1	4	2	3	5	2		**17**	18	21	2	6	23	11	16
Sciaridae			16	7	9	45	16	14	9	3	4	2		**125**	749	53	12	56	33	13	171
Cecidomyiidae														**0**	0	0	0	3	4	32	6
Empididae							1	2		2	2	2		**9**	7	7	8	1	8	10	9
Phoridae						1		1					1	**3**	0	0	0	1	1	2	3
Syrphidae					1	2	1	1					3	**8**	10	12	6	10	4	5	1
Heleomyzidae														**0**	0	0	0	1	2	0	1
Piophilidae														**0**	0	3	0	0	0	0	0
Agromyzidae	2	5	5	1	2		1		1					**17**	99	34	2	3	0	0	0
Tachinidae								1		1		1		**3**	7	10	7	0	2	6	1
Calliphoridae		1												**1**	9	4	1	1	1	4	5
Scatophagidae														**0**	31	11	3	7	0	2	10
Anthomyidae	10	15	9	2	1	1	1		2		1		1	**43**	28	12	10	8	2	*	3
Muscidae				4	16	107	74	62	28	26	22	33	22	**394**	935	1423	866	554	1312	1455	754
HYMENOPTERA																					
Bombus sp.														**0**	7	5	3	1	0	0	1
Ichneumonidae						6	10	10	2			4	1	**33**	68	47	70	24	34	48	24
Braconidae														**0**	0	1	0	0	0	0	0
Chalcidoidea													1	**1**	1	1	1	2	14	0	0
Ceraphronoidea														**0**	0	0	2	0	0	0	0
ARANEA																					
Lycosidae							1	2	8	11	1	6	2	**31**	10	1	1	1	0	2	0
Linyphiidae		2	3				2		1					**8**	12	4	8	8	15	10	6
ACARINA				23	57	#	#	#				#	#	**80**	704	524	54	347	358	246	191
Total	20	29	116	2028	3604	1407	1073	900	274	322	171	210	62	**10216**	9444	7717	9050	9448	7610	10588	9177

Table 3.11. Weekly totals of arthropods etc. caught in the window trap stations in 2006. The station holds two window traps situated perpendicular to each other. Each window measures 20x20 cm. Values from each date represents catches from the previous week. Totals from 1999-2005 are given for comparison. Asterisks mark groups not separated from related group(s) that particular year. '#' mark subplot samples that were not fully sorted for springtails, mites and ticks. Consequently, totals for these species are underestimated.

back to normal numbers after the peak year in 2005, just as scale insects (Coccoidea) were lower than the last two years, and similar to the numbers prior to 2004. Also, chalcid wasps (Chalcidoidea) were lower than 2004 and 2005, yet high compared to preceding seasons (Fig. 3.3). The Ichneumon wasps (Ichneumonidae) were found at record low numbers.

The sheetweb weavers (Linyphiidae) also appeared in the samples at the lowest numbers yet (Table 3.12).

Date	3.6	10.6	17.6	24.6	1.-2.7	8.7	15.7	22.7	29.7	5.8	12.8	18.8	26.8	2006	2005	2004	2003
No. of active stations	**2**	**3**	**3**	**3**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
No. of trap days	**96**	**160**	**168**	**168**	**221**	**258**	**280**	**280**	**280**	**280**	**280**	**228**	**280**	**2979**	**3686**	**3437**	**3101**
COLLEMBOLA	23	80	929	711	617	#	#	#	#	#	643	#	#	3003	9586	13277	17510
HETEROPTERA																	
Nysius groenlandicus								5		1	3		4	13	471	96	3
Aphidoidea	1	1	1		6	9	3	7	14	6	8		5	61	524	277	1624
Coccoidea		9	17	2	12	16	10	72	199	174	66	19	21	617	1092	1288	42
Unidentified Heteroptera	2		1											3			
THYSANOPTERA							1						1	2	19	4	0
LEPIDOPTERA																	
Lepidoptera larvae		1	4	6	7	18	14	14	16	21	5	5	5	116	82	280	37
Tortricidae										1				1	0	0	1
Colias hecla														0	15	38	156
Clossiana sp.						2	2	14	23	63	46	54	6	210	174	240	468
Lycaenidae						1	1	1	2	16	11	11	2	45	0	0	0
Plebeius franklinii														0	1	1	0
Geometridae														0	2	2	0
Noctuidae							2		3	1	3	9	1	19	183	14	110
DIPTERA																	
Nematocera larvae	2		1	10	4	2	1		1					21	10	18	29
Tipulidae larvae					1			1						2	1	6	3
Tipulidae					1	1	1	1						4	5	1	7
Trichoceridae											1			1	0	1	1
Culicidae						6	2	4	12	6	3			33	13	19	23
Chironomidae	1	5	200	837	527	1066	814	544	163	134	45	17	12	4365	1492	1596	4768
Ceratopogonidae	12		4	27	7	28	1	4	2	5	2			92	6	16	107
Mycetophiliidae					1	3	4	52	2	3	5	4		74	104	63	70
Sciaridae	153	3	79	149	82	147	84	150	193	141	40	26	9	1256	819	912	1101
Cecidomyiidae										1	1			2	8	13	8
Brachycera larvae														0	0	0	3
Empididae					1				1					2	3	5	8
Cyclorrhapha larvae					1									1	77	60	23
Phoridae					4	22	33	66	38	130	92	37	39	461	386	461	665
Syrphidae		1	2					1	1		3	1		9	93	45	35
Heleomyzidae						1								1	0	1	1
Agromyzidae		19	2	1	1	2					3	1		29	151	60	10
Tachinidae						2	2	2	3	3	2	1	1	16	39	42	60
Calliphoridae										3	2	1		6	96	31	17
Scatophagidae								1						1	106	7	42
Fannidae														0	0	0	0
Anthomyiidae		57	45	20	9	9	6			5	12	11	9	183	535	124	108
Muscidae			1	37	65	261	250	471	441	397	166	168	56	2313	5464	5623	8385
SIPHONAPTERA														0	0	0	0
HYMENOPTERA																	
Tenthredinidae														0	1		
Hymenoptera larvae														0	3	4	8
Bombus sp.				1		1	3				1			6	18	40	15
Ichneumonidae			1		7	14	14	21	27	46	44	55	40	269	717	720	974
Braconidae		1	1	4	7	6		3	1	11	2	3	3	42	80	61	52
Chalcidoidea	2		1		4	20		13	10	31	54	63	89	287	747	746	120
Scelionidae	1										3			4	0	0	310
Ceraphronoidea			1	1	1	1			3		1			8	17	13	3
Cynipoidae														0	24	3	0
ARANEA																	
Thomisidae	10	16	11	8	16	28	14	14	16	20	6	3	2	164	98	90	164
Lycosidae	16	43	125	92	76	174	189	337	328	296	328	625	240	2869	3316	3428	3438
Lycosidae egg sac						4	5	7	18	10	2	8	2	56	45	69	85
Dictynidae		1			1		1	1	1	2	1		2	10	84	40	18
Linyphiidae	33	99	79	94	180	97	51	42	29	33	30	18	49	834	1411	1483	2526
ACARINA	119	279	1049	715	445	63	81	117	58	73	506	#	#	3505	10096	17616	18602
OSTRACODA			24	50	33	15	6	1						129	1	0	12
NEMATODA			29	88	105	5	5						1	233	1	1	4
ENCHYTRAEIDAE			2	4	1	1	11	1						20	1	0	0
Unidentified			26	32	25	6								89	0	0	0
Total	375	615	2635	2889	2247	2031	1611	1967	1605	1633	2140	1140	599	21487	38217	48935	61756

Table 3.12. Weekly totals of arthropods etc. caught at the five pitfall trap stations in 2006. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous week. Totals from 2003-2005 are given for comparison. Asterisks mark groups that were not separated from closely related groups in that year.'#' mark subplot samples that were not fully sorted for that particular species. Consequently, totals for these species are underestimated.

Table 3.13. Peak ratio (per cent) of female arctic willow Salix arctica catkins infested by sawfly larvae in 1996-2006. '+' indicates that numbers were not quantified.

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Salix 1	+	0	0	43	2	0	0	0	0	0	0
Salix 2	3	0	0	6	0	0	0	0	0	0	0
Salix 3	9	0	0	3	5	0	0	2	0	0	6
Salix 4	0	0	0	1	7	0	0	0	0	0	0
Salix 5	-	-	-	-	-	-	-	0	0	0	0
Salix 6	-	-	-	-	-	-	-	0	0	0	0
Salix 7	-	-	-	-	-	-	-	0	0	0	0

Table 3.14. Peak ratio (per cent) of mountain avens Dryas integrifolia/octopetala flowers depredated by larvae of "black moth" Sympistis zetterstedtii in mountain avens plots in 1996-2006.

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Dryas 1	2	6	3	0	0	0	15	2	15	1	27
Dryas 2	0	5	0	0	0	0	1	0	4	1	3
Dryas 3	11	18	3	0	0	0	7	1	33	10	6
Dryas 4	17	1	7	0	0	0	11	5	39	3	18
Dryas 5	2	8	2	0	0	0	9	2	3	0	2
Dryas 6	0	0	0	0	0	0	0	0	1	0	6
Dryas 7	-	-	0	26	0	0	2	3	0	3	0
Dryas 8	-	-	0	27	0	0	0	11	0	0	0

Table 3.15. Number of woolly-bear Gynaephora groenlandica caterpillars recorded by one observer in study area 1A (the bird monitoring area) in June and July 1996-2006.

Month	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
June	1	2	7	7	10	2	4	25	24	16	2
July	0	1	4	17	2	2	3	2	9	0	11
Total	1	3	11	24	12	4	7	27	33	16	13

Table 3.16. Number of bumble bees Bombus polaris/hyperboreus recorded by one observer in June and July 1999-2006.

Month	1999	2000	2001	2002	2003	2004	2005	2006
June	-	59	12	48	95	243	238	111
July	35	34	15	31	16	107	69	104
Total	-	93	27	79	111	350	307	215

Insect predation on Dryas flowers and *Salix arctica*

For the first time since 2003, sawfly larvae (Symphyta) were feeding on Salix catkins in a study plot (Table 3.13). Also, the percentage of Dryas flowers eaten by "black moth" *Sympistis zetterstedtii* larvae in 2006 was higher than usual, only second to the record-high in 2004 (Table 3.14).

Woolly bear caterpillars and bumble bees

Woolly-bear *Gynaephora groenlandica* caterpillars were encountered both in June and July by the bird observer (J. Hansen), in near-average numbers (Table 3.15). The earliest record of a bumble bee *Bombus polaris/hyperboreus* was 7 June. A total of 215 bumble bees were observed by one observer (J. Hansen) in June and July (see Table 3.16). This is the third highest number observed to date, but is most likely the result of the high number of observing hours. Also, there are likely observer dependent factors to consider (cf. Rasch and Caning 2005).

3.3 Birds

Jannik Hansen, Anders P. Tøttrup and Nette Levermann

Bird observations were made by Niels Martin Schmidt and Martin Ulrich Christensen 26 May-6 June, by Jannik Hansen 6 June-29 August. Other researchers and staff provided much valued information throughout the season.

Observations from Sandøen and Daneborg from 7 July to 3 August 2006 gave supplementary information rarely covered in former ZERO annual reports. Observations were made by Anders P. Tøttrup and Nette Levermann.

For scientific names in this chapter, see the section Other observations. Local site names can be found in Meltofte and Berg (2006).

Breeding populations

A complete initial census was performed between 17 and 26 June, which is later than usual, but comparable to 1999, when large amounts of snow also postponed the initiation of the census. The completion of the survey took 53 'man-hours', which is above average. Most parts of the 19.3 km^2 census area were snow free; although to a much lesser extend than usual. The entire census was performed in good weather conditions. Only one of the long-tailed skua nests were initiated prior to the census period.

In addition, large parts of the census area were covered regularly during June, July and most of August, exceptions being the Aucellabjerg slopes above 350 m a.s.l. and the closed goose moulting area along the coast. The first were covered on only three occasions, due to fog (see below).

The total effort in June and July 2006 (Table 3.17) was similar to recent years. A smaller surge flooding in Zackenbergelven, practically prevented access to the census area west of the river on 27 and 28 July.

The results of the initial census, supplemented with records during the rest of the season (see Meltofte and Berg 2006), are presented in Table 3.18, and in Table 3.19, these are compared with the estimates of previous seasons.

Unlike 2005, sanderlings were recorded in record high numbers, even a little above the previous peak year 2003. Dunlins and ruddy turnstones also appeared in numbers above average. Dunlins have been recorded in numbers between 98 and 120 certain pairs since 2000. During the last five years, the population has varied considerably compared to the first five years of monitoring. For ruddy turnstone, it seems that the population was at a low in 2002 and 2003, and that it has now risen to around the double. Most of these seemingly did not breed this year, which is likely to be associated with the late melting of snow (see Reproductive phenology of waders). Common ringed plover and red knot were recorded in numbers around the average of previous years (Tables 3.18 and 3.19).

The number of long-tailed skua territories was around average this season. Early in the season, higher numbers of birds were observed, possibly due to the fact that many birds were not breeding and therefore moved around a lot. However, the extensive snow coverage probably meant that birds were concentrated in areas with snow free land (Table. 3.18). Only two pairs nested in the census area (See Reproductive phenology and success in long-tailed skuas).

Month	West of river	East of river	Total
June	7; 27.5	16; 83.5	23; 111
July	7; 32.25	16; 92.5	23; 124.75
Total	14; 59.75	32; 176	46; 235.75

Table 3.17. Number of trips and hours (trips; hours) allocated to bird censusing, breeding phenology and hatching success sampling west and east of Zackenbergelven during June and July 2006, respectively.

Species	West of river <50 m a.s.l. 3.47 km^2	East of river <50 m a.s.l. 7.77 km^2	East of river 50-150 m a.s.l. 3.33 km^2	East of river 150-300 m a.s.l. 2.51 km^2	East of river 300-600 m a.s.l. 2.24 km^2	Total
Red-throated diver	1	3-4	0	0	0	4-5
Pink-footed goose	0	0	0	0	0	0
Common eider	0	0	0	0	0	0
King eider	0	1	0	0	0	1
Long-tailed duck	0-1	5-6	0	0	0	5-7
Rock ptarmigan	1-2	2-3	0	0-1	1	4-7
Common ringed plover	8-9	20-29	4-5	5	4-5	41-53
Red knot	0	4-10	15-22	8	0	27-40
Sanderling	8-11	40-47	6-7	12-14	7-8	73-87
Dunlin	23-25	68-83	15-18	0	0	106-126
Ruddy turnstone	7-9	36-41	18-23	2-5	0	63-78
Red-necked phalarope	0	2	0	0	0	2
Red phalarope	0	5-7	0	0	0	5-7
Long-tailed skua	5-7	7-12	8-10	1	0	21-30
Glaucous gull	1	0	0	0	0	1
Arctic redpoll	0	0-1	0-1	0	0	0-2
Snow bunting	17	22-24	23-24	9	9-10	80-84

Table 3.18. Estimated numbers of pairs/territories in five sectors of the 19.3 km^2 census area in Zackenbergdalen, 2006.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Red-throated diver	1-2	3	3	2-3	2-3	2	3	2	3	4-5	4-5
Pink-footed goose	0	1	0-1	2	1	1	1	0	0	0	0
Common eider	0	0	0	0	1	1	1	0	1	0	0
King eider	2-3	2	1	2-3	2-4	3-4	4-6	1	1-2	1-2	1
Long-tailed duck	5-8	4-6	6-8	7-8	5-8	5-7	6-7	7-9	6	6-8	5-7
Rock ptarmigan	3	11-15	4-6	7-8	1-3	2-4	3	0-1	0	0	4-7
Common ringed plover	54-56	40-48	38-45	51-65	41-43	51-54	37-41	29	46	17-20	41-53
European golden plover	0	0	0	0	0	1	0	0	0	0	0
Red knot	33-43	35-44	27-32	25-33	24-27	27-30	24-27	24-25	19	30-36	27-40
Sanderling	50-63	55-70	62-70	60-67	58-66	58-72	49-55	67-74	62	38-49	73-87
Dunlin	69-81	75-91	75-94	80-94	98-103	104-111	120-132	105-114	122	92-102	106-126
Ruddy turnstone	41-51	49-58	56-63	43-49	48-50	45-51	31-37	33-34	50	65-74	63-78
Red-necked phalarope	0-1	0-2	1-2	1-2	1-2	1-2	1-2	1-2	1	1	2
Red phalarope	0	0	0-1	0	0	1	0	0	0	1	5-7
Long-tailed skua	25-29	22-25	21-24	19-24	21-28	22-25	23-26	25-29	21	24-29	21-30
Glaucous gull	0	0	0	0	0	0	0	0	1	1	1
Snowy owl	0	0	0	0	0	1	0	0	0	0	0
Northern wheatear	0	0	1	0	0	0	0	0	0	0-2	0
Arctic redpoll	0	0	0	0	0	0	0	1	3	1	0-2
Snow bunting	45-55	45-56	41-46	52-64	42-47	48-58	58-61	59-61	90-103	114-123	80-84

Table 3.19. Estimated numbers of pairs/territories in the 19.3 km² census area in Zackenbergdalen, 1996-2006.

The last two seasons have shown rising numbers of snow bunting territories, possibly due to extensive snow free areas early in those seasons. This season numbers were lower again, although the 3rd highest numbers (Table 3.19). The distribution of snow seems to be a key factor in the dynamics of these processes.

Reproductive phenology in waders

In terms of nesting, the season of 2006 was a very late year. Only 6.25% of egg laying in all wader nests were initiated before 10 June, just over 78% before 1 July, and medians of the first egg dates were after 25 June in four of the five species (Table 3.20).

The snow cover on 10 June 2006 was extensive (see section 2.2) and nest initiation was fairly late, corresponding to the relationship seen in previous years (Table 3.21).

Reproductive success in waders

Nest success was fairly good for dunlin and very good for common ringed plover, whereas the nest success for sanderling and turnstone was very low. The all-wader-predation rate was c. 63%, which is above average. Thirteen of 28 nests were found predated. Fates of five nests were unknown. All but one turnstone nests were unsuccessful, whereas all common ringed plover nests were successful. Those not being predated were either abandoned (n=1) or predated at, or just after, hatching (n=1). Also, all but two sanderling nests were predated. The Arctic fox is the likely predator of most nests, as no nests were found with clear signs of avian predators. Also, fox encounters were high (Table 3.22).

The mean clutch size was 3.4 in 2006; lower than average for all waders. Mean clutch sizes for the individual species can be found in Table 3.23. Pairs could be economising with egg production given the late start of the breeding season. One turnstone nest and one dunlin nest held only one egg each, and one sanderling nest and three dunlin nests held two eggs. One of four common ringed plover nests, five of 16 dunlin nests, one sanderling nest and one turnstone nest held three eggs. Only one red phalarope nest was found, containing four eggs (see Other observations).

In July and early to mid-August alarming parents – and later juveniles – were found in the fens and marshes (dunlins), on the slopes of Aucellabjerg and in the dry lowlands (common ringed plovers, sanderlings and dunlins). Turnstone youngs – juveniles – was only seen late

Table 3.20. Median first egg dates for waders at Zackenberg 2006 as estimated from incomplete clutches, egg floating, hatching dates, as well as weights and observed sizes of pulli

Species	Median date	Range	N
Common ringed plover	28 June	19 July - 29 July	5
Red knot	-	-	0
Sanderling	30 June	20 June - 10 July	12
Dunlin	27 June	16 June - 4 July	20
Ruddy turnstone	21 June	13 June - 29 June	4
Red-necked phalarope	-	-	0
Red Phalarope	1 July	1 July	1

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Snow cover on 10 June	84	82	76	80	91	53	84	79	83	48	28	
Sanderling		(16 June)	18 June	18 June	23.5 June	16 June	22.5 June	17 June	13 June	8 june	(15 June)	30 June
Dunlin	(18 June)	11.5 June	13 June	16.5 June	22 June	11.5 June	25 June	8 June	12 June	12 June	12 June	27 June
Ruddy turnstone	(12 June)	18.5 June	13 June	12.5 June	24 June	11 June	23 June	9 June	8 June	8 June	11 June	(21 June)

Table 3.21. Snow cover on 10 June together with median first egg dates for waders at Zackenberg 1995-2006. Data based on less than 10 nests/ broods are in brackets, less than five are omitted. The snow cover is pooled (weighted means) from section 1, 2, 3 and 4 (see section 2.2), from where the vast majority of the nest initiation dates originate.

in the season, most often in connection with low tide feeding. Most of these are thought to have been hatched outside the census area.

From 16 July, flocks of up to 12 long-tailed skuas roamed the lower slopes of Aucellabjerg and the lowlands.

The number of juvenile waders in the deltas at low tide was extremely low compared to previous seasons (Table 3.24). Common ringed plover was the only species represented with a near-normal number of juveniles. For the three other species, 2006 had some of the lowest numbers of juveniles in the deltas during low tide counts recorded during the programme. Dunlin and sanderling juvenile numbers have fallen dramatically. In 2006 the former delta was used more than previously, possibly due to a deterioration of the habitat in the present delta where surge flooding altered the surface of the mudflats dramatically in 2005 (Klitgaard et al. 2006). In total, 78% of all waders observed during low tide, were recorded in the former delta; more specifically 71% of all adult waders and almost 93% of all juvenile waders. The waders might simply have chosen other areas to feed in. Minor deltas exist at several rivulet mouths along the coast of Young Sund (for specifik details on distribution within the low tide census area, see each species account under Other observations).

Reproductive phenology and success in long-tailed skuas

In terms of breeding, the season 2006 was late for the long-tailed skuas, and even a little later than 1999 (Table 3.25). The only two nests found within the census area were initiated on the 16 and 22 June, respectively. As mentioned above, the number of pairs was similar to other years, though most pairs seemed to be non-breeding. Apart from the two aforementioned nests, no other breeding attempts (courtship, copulations etc.) were recorded.

Only three lemming observations were made by the bird observer, indicating a moderate lemming season. This was also reflected in the number of winter nests found. Coupled with the many Arctic fox encounters (Table 3.22) and three successful fox litters (Table 3.37) and the late snow melt, this suggests a difficult season for the long-tailed skuas. Each nest held only one egg. The egg of one nest never hatched, although being incubated well beyond the normal hatching period, while the egg of the other nest hatched. Nest predation for long-tailed skuas was consequently low, although nest success can only be said to be half successful (Table 3.25). The only hatched chick is thought only to have lived to a maximum of 10 days.

Possibly, long-tailed skua recruitment was generally low in East Greenland, as no long-tailed skua chick fledged in 2006 at Karup Elv, on Traill Ø, either (B. Sittler, pers. comm.).

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	1996-2006
Common ringed plover				(40)		(62)				-	(0)	33-38
Red knot	-	-			-		-			-	-	(79)
Sanderling	(28)	(0-67)	(22)	60	(54)	81	(77)	55	15-29		(92.6)	49-53
Dunlin			(53-72)	35	32	(25)		37	7	(57)	53	55-59
Ruddy turnstone	(32-79)	0-33	84	72-77	71	(40)	(48)	73-79	17			32-37
Red-necked phalarope	-	-	-		-	-	-	-	-		-	
Red phalarope	-	-	-	-	-	-	-	-	-	-		
All waders	**37-67**	**0-48**	**63-68**	**61-62**	**56**	**57**	**57**	**56-58**	**10-13**	**82**	**63**	**46-51**
N nests	17	27	44	44	47	32	21	47	54	15	28	366
N nest days	163	274	334	521	375	328	179	552	700	104	332	3860
Fox encounters	14	5	7	13	11	14	21	11	16	18	22	

Table 3.22. Mean nest predation (%) 1996-2006 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are given in brackets. Data from species with below 50 nest days have been omitted (-: no nests at all). Nests with at least one pipped egg or one hatched young are considered successful. Also given are total numbers of adult foxes observed by the bird observer in the bird census area during June-July (away from the research station proper).

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean
Common ringed plover	(4.00)	(4.00)	(3.50)	(4.00)	(3.50)	(4.00)	(3.50)	(4.00)	(4.00)	(4.00)		(3.75)	3.84
Red knot				(4.00)	(4.00)		(4.00)		(4.00)	(4.00)			4.00
Sanderling	(4.00)	4.00	3.86	4.00	3.67	4.00	3.43	3.83	4.00	4.00	3.75	3.63	3.85
Dunlin		(4.00)	(3.75)	3.90	3.70	3.93	3.63	(4.00)	4.00	3.92	4.00	3.13	3.81
Ruddy turnstone		3.71	3.79	3.82	3.58	3.80	3.75	4.00	3.77	3.92	3.86	(3.00)	3.73

Table 3.23. Mean clutch sizes in waders at Zackenberg 1995-2006. Samples of fewer than five clutches are given in brackets.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Common ringed plover	96	126	249	42	44	142	320	140	170	253	176	166
Sanderling	304	726	149	333	445	366	540	156	242	346	78	72
Dunlin	325	360	323	232	509	273	326	554	309	308	173	91
Ruddy turnstone	80	108	82	109	23	73	162	183	75	19	52	28
Waders total	810	1342	803	722	1021	854	1351	1040	803	928	479	357

Table 3.24. Total numbers of juvenile waders recorded at low tide in the former and the present deltas of Zackenbergelven during 15 counts performed every third day in the period 18 July - 28 August 1995-2006. Data from missing counts have been substituted by medians from previous and following counts. Please note that the total number also includes numbers of juvenile red knots, which does not otherwise feature in this table.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Median 1st egg date		7.6	12.6	17.6	18.6	15.6	9.6	15.6	8.6	8.6	19.6
No. of clutches found	8	17	23	8	5	21	14	7	21	8	2
No. of young hatched	1	25	16	2	2	18	14	5	36	6	1
Nest success % (Mayfield)		(80.6)	24.1	(18.1)	(17.5)	39.5	44.1	(76.2)	(100)	(51.8)	(100)*
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22	1	0
Lemming winter nests	161	366	721	331	192	326	287	95	431	234	265

*Table 3.25. Egg-laying phenology, breeding effort and success in long-tailed skuas at Zackenberg 1996-2006. Median egg laying date is the date, when half the supposed first clutches were laid. Number of clutches found includes replacement clutches. Mean hatching success according to the modified Mayfield method (Johnson 1979). Poor data (less than 125 nest days or five predations) are given in brackets. Nests with at least one pipped egg or one hatched young are considered successful. Also given, are numbers of lemming winter nests within the c. 2 km^2 lemming census area (see section 3.4). *Please note that in 2006, only one of two eggs hatched (see text).*

No observations of juvenile birds were made in 2006.

Erratum: In ZERO Annual Report for 2005 (Klitgaard et al. 2006), wrong long-tailed skua nest initiation dates were printed. It should read: "In 2005, long-tailed skua nests were initiated between 4 June and 19 June, but only a minor proportion of the population attempted to breed."

Breeding barnacle geese

On 9 June 2006 the colony, rediscovered in 2005, was revisited. No certain signs of activity, but the call of one barnacle goose was heard from the terraces of the southern face of Orienteringsspids – the southernmost peak of Zackenbergfjeld. Two smaller flocks were foraging at the foot of the mountain. From this observation and later observations of traffic towards that part of the mountain, it is assumed that some, if modest, breeding activity took place here again in 2006.

The first family with a gosling was seen on 30 June in the former delta, foraging with seven other adults. The number of broods was among the lowest recorded (Table 3.26), and the maximum number of goslings seen at one time, was only four, as opposed to 35 in 2005.

In adjacent areas, very few young were seen. On 16 July, two families with one and two young, respectively, were observed with four other adults and 112 immatures near Halvøen.

No goslings were recorded among the 513 barnacle geese seen during the line transect in Store Sødal (Table 3.27)

The mean 2006 brood size equals the lowest in the ultimo July figures, with only 1.1 young per brood. From Isle of Islay, Western Scotland, it was reported that the percentage of young in the flocks arriving to their wintering quarters also

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Primo July		(3.0)	3.1	(2.9)	1.9	(3.2)	(1.8)	2.4	(1.8)	2.6	(1.7)	(2.0)
Medio July		(2.3)	2.7	2.3	1.8	(3.1)	(1.7)	2.4	(1.2)	2.3	2.7	(1.5)
Ultimo July	(2.0)	(3.0)	2.6	2.2	1.7	3.1		2.3	(1.1)	2.3	(2.2)	(1.1)
Primo August	(2.3)	(2.3)	2.4		1.8		(2.0)	2.2	(1.2)	(1.9)		(1.5)
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26	14	9
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59	2.35	1.67	1.15
Per cent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4	15.9	6.3	3.23

Table 3.26. Average brood sizes of barnacle geese in Zackenbergdalen during July and early August, 1995-2006, together with the total number of broods brought to the valley. Samples of less than 10 broods are given in brackets. Average brood size data from autumn on the Isle of Islay in Scotland are given for comparison, including the percentage of juveniles in the population, by courtesy of M. Ogilvie, pers. comm.

was very low (Table 3.26; M. Ogilvie, pers. comm.)

Line transects

This year, the line transects were undertaken 16-18 July through Store Sødal, whereas snow conditions did not permit the Daneborg - Zackenberg route to be surveyed.

In Store Sødal, more barnacle geese than normal were recorded (Tables 3.27 and 3.28), even higher than last year. The last couple of years, however, fewer and fewer pink-footed geese have been sighted in upper Store Sødal.

Consistent with the numbers from the census area, more rock ptarmigans were recorded on this year's Store Sødal transect. Also, higher numbers of common ringed plovers and dunlin are notable. The absence of ruddy turnstones is surprising, but could be a result of a failed breeding season. The numbers of Arctic terns and snow buntings are the highest recorded on any transect in Store Sødal.

Most surprising is the complete absence of records of young of all but rock ptarmigans. Not even the species with high reproductive success within the census area were recorded with any young in Store Sødal this year.

Sandøen

From 7 July to 3 August 2006 Nette Levermann and Anders P. Tøttrup stayed on the island Sandøen. During this period the ice cover was present for a long period, and did not break up until 23 July.

Eiders were present throughout the study period (see Fig. 3.4). Males were present until 15 July, hereafter only very few males were seen. The number of females increased after the observation of the first pullus. Pulli was seen from 21 July and numbers increased to just fewer than 100 on 31 July.

This year, the breeding attempt failed probably caused by regular disturbance by an Arctic fox. Some of the breeding birds did lay eggs as we found close to 20 abandoned nests and a number of predated eggs on the island.

After the sea ice broke there were still up to 12 females showing pre-breeding behaviour (making nests cups and resting on the central plateau). However, the late

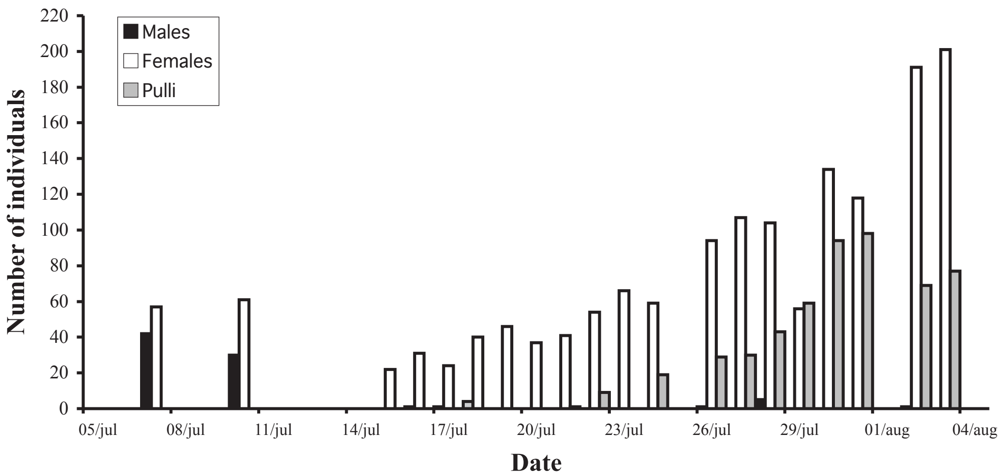


Fig. 3.4. Eider abundance divided into males (black), females (white) and pulli (grey bars) around Sandøen during July and August 2006.

Table 3.27. Birds recorded (adults; young) during line transect surveys through Store Sødal to Zackenberg (see map in Meltofte and Berg 2006) in mid July 2006. The line transect survey from Daneborg to Zackenberg was not undertaken this season.

	Store Sødal 16-18 July
Red throated diver	6
Great northern diver	0
Pink-footed goose	8
Barnacle goose	513
Common eider	0
Long-tailed duck	1
Rock ptarmigan	3;4
Common ringed plover	84
Sanderling	14
Dunlin	106
Ruddy turnstone	0
Arctic skua	0
Long-tailed skua	6
Glaucous gull	14
Arctic tern	15
Common raven	1
Snow bunting	134

season probably hampered further breeding attempts. Most likely, all pulli seen originated from the mainland colony at Daneborg.

Eiders may benefit from the protection effect the colony of Arctic terns provides on predators such as the larger gulls, and the surrounding shallow waters of Sandøen offer good feeding opportunities. Thus, Sandøen seem to be an important resting area for moulting females and their pulli for the eiders population in the southern part of Young Sound.

Sabine's gulls and Arctic terns also experienced hard predation by Arctic fox, and suffered complete breeding failure. Up to 67 pairs of Sabine's gull attempted to breed, but no eggs were observed. A total of four Arctic tern eggs were found from up to 311 pairs of Arctic tern. All eggs were abandoned or predated. For a more detailed description of this year's conditions, see section 5.8 and Levermann and Tøttrup (2007).

Two other species were seen in pre-breeding behaviour that never amounted to actual breeding: long-tailed duck and glaucous gull.

For other bird observations from Sandøen, see "Other observations" below. It is the first time in years that we have data of high quality from Sandøen.

Other observations

Two supposed observations of rare species were considered too uncertain to accept as records; a doubtful snowy owl (Nyctea scandinavica) and an alleged northern diver (Gavia immer).

Red-throated diver *Gavia stellata*

The first red-throated diver arrived in Zackenberg 4 June (Table 3.29), although two observations of a single unspecified diver flying high above the research station were noted on the 2 and 3 June.

The first pair to settle was a pair in Gadekæret on 6 June. All in all, the season had four to five pairs attempting to breed

Table 3.28. Total number of birds recorded (adults; young) during line transect surveys through Store Sødal to Zackenberg, mid-late July 1997-2006. The line transect survey from Daneborg to Zackenberg was not undertaken this season. Brackets denote interpolated figures.

Species	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Red-throated diver	3	2		2	3	5; 1	6; 1	3	6	6
Great northern diver				2; 1					2	
Pink-footed goose	263	123	27	56	85	37	38	20	36	8
Barnacle goose	182	250; 23	227; 23	261; ≥14	260; 1	138	201; 36	12; 6	331; 6	513
Goose sp.	25									
Common eider	390	119; 5	55; 6	10	11; 6	7	15; 7	22	10	
Long-tailed duck	13		2				1	3	1	1
Rock ptarmigan	2	1				1; 2		2	4;1	3;4
Common ringed plover	71	70	(78)	(105; 4)	63; 1	54	54	45	62	84
Red knot	1			3			1	3; ≥2		
Sanderling	14; 1	10	33	11; 6	12	25; 4	9	12; 3	1	14
Dunlin	64; 1	62; 1	(56)	48	62	33; 8	60	28; ≥10	55	106
Ruddy turnstone	6	8	8	6	2	5; 2	8	5; 1	2	
Arctic skua						2		3	3	
Long-tailed skua	13	9	14	4	21	12	6	30	15	6
Glaucous gull	11	11; 2	8	(7)	10	101	12	13	20	14
Arctic tern	3	9	1	3	8	6	2	3	7	15
Snowy owl					1; 3					
Northern weathear							3			
Common raven	10	9	2	(5)	4	7	9	15	2	1
Arctic redpoll								1		
Snow bunting	104	64; 2	(54)	(30; 6)	110; 1	48; 10	116; 47	44; 43	119; 2	134

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Red-throated diver	≤3.6	30.5	3.6	4.6	6.6	3.6	1.6	≤4.6	≤1.6	29.5	4.6
King eider	12.6	4.6	15.6	16.6	≤22.6	9.6	11.6	≤13.6	14.6	21.6	12.6
Long-tailed duck	≤1.6	30.5	2.6	6.6	6.6	7.6	3.6	7.6	2.6	1.6	7.6
Red-necked phalarope	5.6	30.5	5.6	10.6	7.6	4.6	5.6	11.6	≤1.6	27.5	6.6

Table 3.29. Dates of first observation of selected species at Zackenberg 1996-2006.

within the census area. Two nests were found, both initiated in mid-July, which is rather late. No nests were successful, and no replacement clutches were recorded. Arctic foxes are the most likely predators of these nests.

In adjacent areas, red-throated diver pairs were recorded in Østersøen, Store Sødal, Morænebakkerne and Lindemandsø. In Lindemandsø one observation of a possible young diver could not be confirmed. Previously, no diver pulli were observed only in 1999 and 2005 (Meltofte 2006).

Red-throated divers started to form smaller flocks 15 July, culminating in the largest number of birds, on 27 August: Ten in the present delta and five in Zackenberg Bugt at the same time. The following day, four red-throated divers were still present in Zackenberg Bugt; the day of departure for the bird observer.

At Sandøen, this species was recorded from 16 to 30 July with one to five adult individuals. On 17 and 18 July four birds migrated north. At Daneborg, a migrating bird was seen on 4 August. See also section 5.8.

Northern fulmar *Fulmarus glacialis*

A single fulmar was seen over Young Sund between Daneborg and Grønnedal on 20 August. The northern fulmar is common along the coast and occasional in fjords during summer (Boertmann 1994).

Pink-footed goose *Anser brachyrhynchus*

Six pink-footed geese were recorded migrating northwards at the arrival of the first observers, 26 May.

During the first period of northward migration, only few individuals stayed in the area briefly. Two foraged in a fen near the research station for several days, and up to eight individuals foraged in the same fen on 31 May and 1 June. Again this year, no pink-footed geese bred at Zackenberg.

Immature pink-footed geese were recorded on northward moulting-migration from 8 June to 3 July. The total migrating number of recorded birds was 532, which is near half the usual migrating number. A few days of fog during the period probably affected this number. The counts of migrating pink-footed geese are collected unsystematically. It is thought that these immatures on moulting migration go further north than they used to do (Christensen 1967, Boertmann and Glahder 1999, Bennike 2007), as a result of population growth (see below).

Moulting immatures were seen from 13 July, where three were seen in the former delta, followed by 21 moulting at Halvøen on 16 July. In adjacent areas, one immature was seen with 30 immature barnacle geese at Hjertesø in Morænebakkerne on 12 July. In total, only 39 immatures were recorded in the study area this year, the lowest number recorded so far (Table 3.30). Numbers have been steadily decreasing since the start of the monitoring programme at Zackenberg, possibly due to human activity. This season's construction activities at the research station might have affected even further (see Barnacle geese, below). It does not seem to reflect any decline in the population, as numbers seem to be steadily increasing elsewhere (Worden 2006).

Southward migration was first sighted as early as 11 August, with ten flying over the former delta, peaking on 27 August, with 34 flying over the present delta. In total, 75 individuals were recorded on southward migration. Local birds congregated from 11 August, nine at Halvøen and six at Lomsø. The highest number of birds congregating for migration was seen on 26 August, when 113 landed in a fen just south of the research station.

In other areas, pink-footed geese were recorded as follows: On 5 July, 28 pink-footed geese migrated northwest and two moved southeast at Daneborg, and on 12 July, a reconnaissance flight revealed app. 50 immatures at Myggbukta.

Barnacle goose *Branta leucopsis*

Twenty barnacle geese were present in Gadekæret at the opening of the station 26 May. During the last days of May and the

Study area	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Pink-footed Goose												
Closed moulting area and further east	310	246	247	5	127	35	0	30	41	11	17	27
Transect Daneborg - Zackenberg	0	0	0	0	0	0	0	0	0	20	0	-
Coast west of closed area	230	40	60?	0	29	0	0	0	0	10	0	3
Upper Zackenbergdalen	0	0	15	0	0	0	0	0	0	0	0	1
Outer Store Sødal	20	12	21	0	5	0	16	8	11	0	2	8
Inner Store Sødal	20	55	144	123	21	56	69	28	27	-	34	
Pink-footed Goose total	>580	>353	<487	128	182	91	85	66	79	>41	53	39
Barnacle Goose												
Closed area at Lomsø and Kystkærene	21	0	29	21	60	84	137	86	120	81	87	148
Coast east of closed area	>120	150?	96	55	66	0	109	80	45	0	2	218
Coast west of closed area	0	0	0	0	0	30	0	0	0	0	29	29
Upper Zackenbergdalen	41	85	2	75	<57	27	60	0	14	0	25	30
Outer Store Sødal	114	46	97	114	117	150	150	81	78	81	161	108
Inner Store Sødal	>19	61	63	184	87	78	46	57	71	-	108	389
Barnacle Goose total	>315	<342	287	449	<387	369	502	304	328	<162	412	922

Table 3.30. The number of immature pink-footed geese and barnacle geese moulting in the study area at Zackenberg 1995-2006. The close area is zone 1c (see http://www.zackenberg.dk/grafik/MapZoner.jpg).

first 7 days of June, numbers of barnacle geese feeeding in the fens near the research station varied from 10 to 40, and flocks of 4-20 flew north each day during this time.

Mid-June a rising number of flocks were seen around the valley, roosting and foraging in the fens – particularly in Gadekæret.

The first larger flocks of immature barnacle geese congregated 4 July, with flocks up to 148 in Lomsø and Kystkærene and 45 at Zackenberg Bugt. In early July, most immatures were within the protected area (1c) at Lomsø and Kystkærene, but during mid-July about a third of them had switched to the area west of this area, mainly the deltas and Zackenberg Bugt. In early to mid-August, most immatures had overcome flightlessness, and soon departed. Thirty immatures were seen on Hjertesø in Morænebakkerne 7 July and two flocks of a total of 218 immature barnacle geese were seen at Halvøen on 16 July. In Store Sødal a high number of immature geese were seen, markedly above the usual level (Table 3.30). All birds seen were flightless and sought refuge on the lake as the observers approached (N. M. Schmidt and M. U. Christensen).

The period of construction work at the research station resulted in heavy helicopter traffic (see Section 6), which visibly disturbed the geese on Lomsø. The helicopter pilot kindly made observations during the flights, and told us that approximately 40 geese stayed on Lomsø, the rest went out on Young Sund. Also, he noted that the first flights over Lomsø made the geese panic. Later they were lying in the farther end of the lake in relation to helicopter route. It is probably safe to assume that the geese were still negatively affected by the over flying helicopter. It is well documented that goose populations are heavily affected by helicopter disturbance, measurable in e.g. body condition – barnacle geese less so than pink-footed geese (Mosbech and Glahder 1991). Miller (1994) suggested that varying the routes would minimalise disturbance.

From 2 August, barnacle geese started to congregate and fly out of the Young Sund area, to start the southbound migration. On 11 August, 114 roosted in the former delta, 12 August 200 roosted at the foot of Aucellabjerg, and on 16 August 127 roosted in the fens south of Aucellabjerg. On the 23 August 374, and approximately 400 on the 24 August, roosted in the same area. Numbers fell after that, and the 117 roosting in Solkæret on 28 August was the last larger group seen before the observers left the station.

From 4 August flocks varying from 10-100 individuals were seen on southbound migration, peaking at approximately 100 on 20 August. The migrating total of 238 individuals is a fairly average number compared to previous seasons, although it started early (cf. Meltofte 2006). These data were collected unsystematically.

In other areas, three flocks totalling 118 barnacle geese had congregated in the inner part of Grønnedal, Calvering Ø on 19 August. The following day, 240 barnacle geese were counted in the outermost part of Grønnedal.

Canada goose *Branta canadensis*

For the first time at Zackenberg, Canada geese were observed in the summer of 2006. The first one was observed 29th May, in a small opening in the ice at Trekanten with a flock of seven Barnacle geese. On 14 June, two Canada geese were videotaped while foraging in fens south of the research station. Lastly, three pairs were foraging and calling at Kystkærene 24 June. No breeding attempts were observed.

Three subspecies of Canada geese are known from Greenland (Boertmann 1994). The ones from Zackenberg probably belong to the largest subspecies, interior, as these were markedly larger than the barnacle geese. The Canada goose – ssp. interior specifically – is expanding dramatically in West Greenland, but is still uncommon in Northeast Greenland (Boertmann 1994). It has been recorded as far north as Danmarkshavn (Forchhammer 1990).

Common eider *Somateria mollissima*

On 12 June, a Somateria sp. female was seen flying up Zackenbergelven, likely to be a common eider. Four days later the first definite common eider female was seen in the current delta. In the following month pairs and smaller flocks were seen regularly, at no time more than 16 individuals (14 females, 2 males on 21 June).

No nests were found, and only one female was encountered on the ground inland. The first young were recorded as late as 7 August, where a female lead four ducklings, in the former delta. Later in August (23-27), a female was seen in the same area with first four, later two ducklings. These young were smaller than the ones from 7 August, and assumed to be the 2nd brood seen this season.

At Daneborg, the common eider colony between the dog pens was once again counted by the Sirius Dog Sledge Patrol. This year a large proportion of the area usually used by common eiders for nesting was under snow during the period of nest initiation, which probably accounts for the low number of breeding birds: 1554 nests. An estimated 15-20% of all females had no nest (Sirius Dog Sledge Patrol, pers. comm.). The last adult male was seen on 8 August.

For observations of common eiders at Sandøen, see the 'Sandøen' section above.

King eider *Somateria spectabilis*

King eiders arrived at Zackenberg on 12 June, when one female was seen in Gadekæret (Table 3.29).

On 24 June the only male – with two females – was seen on Lomsø. Since then, one female in the former delta 30 June, 2 females in Sydkærene 2-3 July, four females on Young Sund near the former delta 8 August and two females at the same place 23 August, are the only observations. This is a low number of observations, but not the lowest. Just 1-2 territories were found, although it is unlikely that they started nesting.

Long-tailed duck *Clangula hyemalis*

The first observation of long-tailed ducks at Zackenberg in 2006 was a pair on a pond near the research station, 7 June (Table 3.29).

One brood was observed in the census area during the season, plus two broods in adjacent Morænebakkerne – Vesterport Sø and Langemandssø, respectively. Broods were recorded from 30 July to 11 August, and were not newly hatched. At least 11 young were expected to have survived to fledging.

From mid-July, long-tailed ducks began congregating in the open water areas of Young Sund and on Lomsø primarily, before starting migration (also, see below for Sandøen congregations). The highest number at any one time was 42 in an open water area along the coast on 16 July. The last observation was 15 August, three long-tailed ducks in Lomsø.

At Sandøen, long-tailed ducks were present from 7 July to 3 August. Up to five females were observed from 7 July to 2 August showing pre-breeding behaviour. This species is known to breed in small numbers on Sandøen (see annual reports from previous seasons). This year breeding attempts were probably given up due to regular visits by an Arctic fox. Larger flocks included six birds (three females) 10 July and 11 individuals present 16 July (six females).

Gyr falcon *Falco rusticolus*

The species visited Sandøen on 22 July, where one adult – possibly a female – took a Sabine's gull sitting in the middle of the colony.

Rock ptarmigan *Lagopus mutus*

After a string of years with low numbers, the rock ptarmigan population increased this season. At the opening of the station, many rock ptarmigan remains were found at the active Arctic fox dens and other parts of the valley. From the remains, we can conclude that foxes took a minimum of 19 rock ptarmigans during the season within the bird census area. At dens in adjacent areas, remains of an additional minimum of four rock ptarmigans were found.

Also, this season five territorial males were seen in the census area (one only heard once early in June), in addition to three territories in adjacent areas. During the census, 4-7 pairs were registered. The nest of one of these pairs were found, containing eight eggs, that all hatched. The brood was seen on 17 July for the first time, and survived at least another day, then disappeared. The nest was found along the eastern bank of Zackenbergelven, north of the research station, as opposed to the slopes of Aucellabjerg and Zackenbergfjeld, where the last broods were seen in 2003 (Rasch and Caning 2004). The re-emergence of breeding rock ptarmigans in the census area fits well with the expected cycles and synchrony for this species in Northeast Greenland (cf. Hansen and Meltofte, in prep.)

Common ringed plover *Charadrius hiaticula*

On 27 May, the day after the opening of the station, six common ringed plovers were foraging in a fen near the research station. Pre-breeding flocks were seen until 19 June, although the first site claiming birds were reported 12 June. Also on 12 June, the largest pre-breeding flock of 12 was seen in a fen near the research station.

On 16 August, a pair was alarming with fully fledged juveniles.

Only small and few post-breeding flocks were seen outside the low tide feeding areas. The first three post-breeders were seen on 17 July, followed by several smaller flocks. The last adult seen outside the low tide areas was seen at Gåsesø 27 August.

During the low tide counts, the highest number of adult birds was 30 in the former delta on 27 August, together with 140 juveniles counted in the same area (also the peak number during the low tide counts of 2006). Juveniles were recorded in the low tide areas from 11-27 August.

As for all waders, common ringed plovers utilised the low tide areas in the former delta more than the ones in the present delta (see Reproductive success in waders, above). More than 95% of all common ringed plovers observed at low tide were observed in the former delta. For adults and juveniles, 88% and 98% were observed in the former delta, respectively. On 5 July, two pairs were seen at Daneborg showing display indicating breeding attempt.

Eurasian golden plover *Pluvialis apricaria*

One golden plover was photographed near the research station on 31 May. This is the 9th season since 1995 with a golden plover sighting. Most observations over the years were from the first half of June, and this observation is the 2nd earliest at Zackenberg.

Red knot *Calidris canutus*

Ten red knots were present at the opening of the research station, 26 May, one singing at the foot of Aucellabjerg. In the following week red knots were singing on the slopes of Aucellabjerg and in the lowlands.

The first pre-breeding flock was foraging in a fen near the research station on 1 June. Pre-breeding flocks were seen until mid-June, when apparent non-breeding flocks appeared. Throughout late June red knots were mainly seen in flocks of eight to 22 individuals. There seemed to be little breeding activity and it is with some caution we determine the change from pre-breeding flocks to non-breeding flocks.

Three colour ringed birds were seen, although only one code was recorded. All three birds are expected to be from the ringing efforts of a Dutch team in 2003 (cf. Rasch and Caning 2004).

It is hard to determine if any post-breeding flocks occurred as they were likely to be masked by the non-breeding birds. Only one bird was seen in August, outside the census area, 2 August. No red knots were encountered during the low tide counts.

This species was present on Sandøen on seven dates during the period 7 July to 2 August. The highest numbers were six on 7 July and ten birds on 16 July. All birds were adults in summer plumage.

Sanderling *Calidris alba*

The first two observations are of two birds each, on 30 May, feeding in two barely snow-free fens. Pre-breeding flocks were seen from 31 May, most often in mixed wader flocks, with up to six individuals. Like the red knot, some pre-breeding flocks occurred into mid-June. Also, foraging between the houses of the research station occurred in small flocks as late as 27 June, likely to reflect the difficult foraging situation caused by late snow melt.

At least 5 different sanderlings with metal rings were observed this season, three of which were birds of the greyer plumage variety.

On 19 July, the first post-breeding flocks were seen, both single and multi-species flocks. Only four small flocks were seen during the rest of the season.

The peak numbers of adult sanderlings at low tide was 94 birds on 25 July. Adult numbers fell dramatically in early August, although even at the last count on 27 August, one adult was still present in the former delta. For juvenile sanderlings, the peak number was recorded 27 August, 53 juveniles in the former delta. The first juveniles did not appear in the deltas until 14 August. It is noteworthy that just over 71% of the sanderlings were recorded in the former delta – more specifically 66% of adult sanderlings and 94% of juvenile sanderlings fed in this delta, rather than the present delta. The main difference compared to previous seasons, is the low number of birds in the present delta (see Reproductive success in waders, above).

The sanderling was the most regular wader on Sandøen, with daily observations of one to 11 individuals during the entire fieldwork period. The highest numbers were seen on 16 July and 21 July with ten and 11 individuals, respectively. All birds were adults in summer plumage.

Pectoral sandpiper *Calidris melanotos*

The third record of this species at Zackenberg appeared in the fens of Sydkærene on 6 July. Most likely, it was the same individual, presumably a female, that was found in Gadekæret 7 July.

In 1998 and 2002, Hans Meltofte found pectoral sandpipers in the census area (Rasch 1999, Rasch and Caning 2003). All previous birds were females. The pectoral sandpiper is a rare guest to eastern Greenland (cf. Boertmann, 1994).

Dunlin *Calidris alpina*

From 26 May to 19 June flocks of pre-breeding birds were seen in the area. By 13 June, most birds had spread out and only very few were still in flocks. Already at the opening of the station, 26 May, a male was singing.

Only one bird with a metal ring was observed this season.

From 19 July to 5 August, few post-breeding flocks were seen. Most congregations were found at low tide, and from 17 June counts were undertaken. From 17 June to 27 August, adults were found, peaking on the first day with 100 adults – all in the former delta. Juveniles were observed at low tide from 22 June onwards, peaking at 48 individuals on 27 August. It is expected that the number could have peaked even higher later in the season.

The former delta seemed a better habitat than the present delta this season: 77% of low tide observations of dunlins were from the former delta. In detail, almost 73% of all adults and 91% of all juvenile dunlins were observed here. In the inland, only few smaller flocks of juveniles were recorded during mid- to late August. At Sandøen, single birds of this species were registered on six dates during 11 July to 23 July, except for two individuals that were seen on 22 July. All birds were adults in summer plumage.

Ruddy turnstone *Arenaria interpres*

The first three ruddy turnstones were seen on 27 May, at the arrival of the first observers. Most pre-breeding flocks were seen until 16 June, although a few even until 19 June. No more than seven ruddy turnstones were seen in one flock, in the beginning often multi-species flocks.

Only were few pairs seemed to breed. Territoriality was common early in the season, but faded out rapidly, and most birds seemed to be non-breeders. Already in late June a few small flocks began to gather. From 2 July, observations of ruddy turnstones became fewer and further between. Seven birds flying over the upper slopes of Aucellabjerg on 9 August was the largest flock, and the last observation of a ruddy turnstone was the only inland observation of juveniles, two flying, 23 August.

Low tide observations of ruddy turnstones were few, most likely because most birds, as non-breeders, had left before our low tide counts had started. Only five adults were seen during these counts, three of them in the present delta. For juvenile ruddy turnstones, the former delta held more observations than the present delta, in line with the other waders (see Reproductive success in waders, above).

Almost 61% of the ruddy turnstone juveniles were observed here. The first juveniles appeared in the low tide counts on 8 August, and were recorded continually until the last count on 27 August.

At Sandøen, this species was seen on seven dates, from 16 July to 30 July, with six birds on 16 July as the highest number. All birds were adults in summer plumage.

Red-necked phalarope *Phalaropus lobatus*

The first birds, a pair, appeared on a pond near the research station on 6 June (Table 3.29). The female was seen at the pond until 9 June. On 13 June a pair appeared in the same pond again, staying until at least 19 June, while a different pair was seen on a pond just south of the research station on 17 June.

From 24 to 28 June a female was back at the pond near the research station, accompanied by a male on 25 and 26 May. It is presumed it was the same female.

A female was seen in the ponds south of the research station, from 2 to 6 July, with two males – copulating with one of them – on 3 July. No nests were found.

The last observation was a female at the southern ponds, 23 july.

Red phalarope *Phalaropus fulicarius*

For the first time in the time of the monitoring programme, a red phalarope nest was found early on 3 July. The nest was in laying with two eggs, being completed on 4 June. The nest was found depredated on 23 July (further details; see Hansen *et al.* in prep.)

The first observation of red phalarope was recorded 18 June, when a pair was seen in a fen near the research station. Mating was observed. The pair was seen regularly until 3 July – at times accompanied by other red phalaropes. On 24 June, four females and three males were recorded in this fen. Also, single males or pairs were seen in three other localities. The last confirmed observation of a red phalarope was a female in a fen south of the research station on 23 July. A description of a red wader with yellow bill from 7 August is likely to be a red phalarope as well.

A total of 5-7 pairs were seen this year, higher than ever before during the BioBasis programme. Possibly, the late snow melt and short season gave better conditions for this high-arctic breeder.

From Sandøen came three observations of single individuals from 11-18 July. All were adult summer plumage birds.

Arctic skua *Stercorarius parasiticus*

In the early morning of 22 July, one Arctic skua was observed in the former delta during low tide.

Another Arctic skua was seen over Young Sund, between Daneborg and Grønnedal on 29 August. Arctic skuas were seen daily at Sandøen, between 7-31 July. A minimum of four birds were seen on 7, 21 and 26 July. During the remaining days, one to three individuals were noted.

Arctic skuas are more common nearer the coast of Northeast Greenland than they are in the fjord areas, and also have a more southerly distribution than the long-tailed skua (Boertmann 2003).

Long-tailed skua *Stercorarius longicaudus*

Very few pairs seemed to be breeding this season. Only two nests were found, and a third couple was seen in courtship. None of the other pairs were seen in courtship or pair bonding behaviour. Post-breeding gatherings started as early as 16 July. The largest flock was seen on 28 August, when a flock of twelve birds were flying over the river crossing, while a flock of eight long-tailed skuas were recorded at Ulvehøj at the same time.

In 2004, a record number of young long-tailed skuas hatched, and this year they would be returning as 3rd calendar year birds. On 19 July a 3rd calendar year bird was seen in a flock with 11 adults. In the following days until 4 August, two more observations of two 3rd calendar year birds were registered. We find it likely to be the same bird, as details in the plumage were identical. The favourable breeding season of 2004 (Rasch and Caning 2005) gave us the expectation that we would see many 3rd calendar year birds in 2006. Immature birds only rarely return to their native tundra until their 3rd calendar year (cf. de Korte 1984). However, 2nd calendar year birds do return to the tundra occasionally. At Zackenberg, a similar number of 2nd and 3rd calendar year birds have been sighted during 1995-2006: five to six 2nd calendar year and five to seven 3rd calendar year immatures so far.

Six long-tailed skuas were seen during the line transect in Store Sødal (Table 3.27).

From 15 July this species was a regular visitor to Sandøen and surrounding waters. On 24 July, four birds were seen as the highest number registered.

Sabine's gull *Larus sabini*

One 2nd year bird was seen on three dates: 22, 27 July and 2 August. See 'Sandøen' above, section 5.8 and Levermann and Tøttrup (2007) for more information on the colony and this seasons breeding failure.

Black-headed gull *Larus ridibundus*

On 28 July, this uncommon visitor to Northeast Greenland was seen on the sea west of Sandøen. According to Boertmann (1994) there have only been 26 records north of Liverpool Land of this species.

Lesser black-backed gull *Larus fuscus*

The first individual of this species flew over Zackenbergelven on 23 June. The highest number of lesser black-backed gulls at Zackenberg came on 27 July when three were standing in the present delta with 87 adult and three 2nd calendar year glaucous gulls following a visit to the other estuary by narwhals (see glaucuos gull). One remained in the current delta the following day.

From 6 – 30 July, one to three adult birds were seen at Sandøen on eight different dates. No breeding attempts or behaviour suggesting breeding was observed. The birds visited the island shortly, spending most of the time on the ice north of the island. On 4 July, one adult bird was seen at Daneborg. The species is steadily expanding northwards in East Greenland (Boertmann, in prep.).

Iceland gull *Larus glaucoides*

Two Iceland gulls were seen among 60 glaucous gulls in the present delta at low tide on 25 July. This is the first record of Iceland gull at Zackenberg since the beginning of the monitoring programme.

The distribution of Iceland gull in east Greenland usually does not go further north than the Tasiilaq area (Boertmann 2003), which makes this one of the northernmost observations in East Greenland, although it has been observed as far north as Hochstetter Forland (Meltofte 1976).

Glaucous gull *Larus hyperboreus*

Glaucous gulls were present at the opening of the station, and the species was recorded almost daily until the bird observer left the station on 27 August.

For the third consecutive year, a pair of glaucous gulls nested on a stony island in Zackenbergelven at Vesterport. The pair was seen at the site the first time on 21 June, initiating incubation prior to 3 July. No further breeding attempts were recorded.

On 24 August, the first two juveniles were seen in the present delta – possibly the one from the nest on the stony island. Two juveniles were recorded again in the same delta on 26 August. The following day, only one juvenile was recorded in the present delta.

From 13 July, birds congregated in the present delta, peaking on 27 July with 90 birds. This peak coincided with the visit of narwhals (see Mammals).

Glaucous gulls were common at Sandøen throughout the season, with as many as 92 individuals registered on 24 July. At the central plateau, one pair was giving alarm calls from 30 July to 3 August.

At Daneborg, 15-20 individuals were registered, mainly around the eider colony. Numbers dropped as the eiders began to leave the colony. One pair made alarm calls and sat in a potential nest in early July at Kap Berghaus.

Great black-backed gull *Larus marinus*

At Sandøen, a single adult was seen on 8 and 9 July, and an immature 11 July. On 1 August, one immature was seen at Daneborg. The great black backed gull is a rare visitor to Northeast Greenland (Boertmann 1994).

Black-legged kittiwake *Rissa tridactyla*

Two adults of this non-breeding visitor were seen on 29 July on Sandøen. The black-legged kittiwake is not an uncommon visitor to Northeast Greenland in late summer (Boertmann 1994).

Arctic tern *Sterna paradisea*

Fifteen Arctic terns were recorded in inner Store Sødal this summer (see 'Line transects' above).

From 16 July to 2 August, a 2nd calendar year bird was seen at Sandøen. The bird was observed displaying and forming a pair with an adult bird on 18 July. See 'Sandøen' above, section 5.8 and Levermann and Tøttrup (2007) for more information on the breeding failure of Arctic terns on Sandøen in 2006.

Meadow pipit *Anthus pratensis*
A possible meadow pipit was seen at the research station 18 June, and on 13 July an adult was resting on the roof of the boat shack at the trapping station. This is only the third year meadow pipits have been observed at Zackenberg. In East Greenland, meadow pipits have not been observed any further north than Zackenberg (cf. Boertmann 1994).

Northern wheatear *Oenanthe oenanthe*
Only one observation of one individual: 18 August at the western bank of Zackenbergelven at the river crossing. This is the second year running with one observation after some years with no wheatears recorded at Zackenberg. Up until 1999, the bird census area had breeding pairs of this species.

Common raven *Corvus corax*
Ravens were seen from 27 May, and at least two pairs were recorded. The first five young birds were seen on 30 July on the slope between the research station and Zackenbergelven. During August, this flock was seen regularly around the valley, with numbers varying from three to six.

From 24 July and onwards at least one raven visited Sandøen regularly. On 24 July, eight individuals were counted on the ice north of Sandøen. In total, the species was recorded on 15 dates during the period 7 – 30 July.

At Daneborg, common ravens are very abundant, and the highest number recorded in the summer of 2006, was 32 birds on 13 July.

Arctic redpoll *Carduelis hornemannii*
On 10 June one Arctic redpoll flew by, calling, at Hestehale Sø in Morænebakkerne, just outside the bird census area. Within the census area, only two observations were recorded this season: One calling, in flight, north of Kystkærene on 24 June, and another, also calling in flight, in Oksebakkerne on 26 June. This is a relatively low number of observations compared to most years, where single birds have been seen regularly in the census area.

Lapland longspur *Calcarius lapponicus*
One male calling and foraging was videotaped in Rylekærene, 23 June.

Snow bunting *Plectrophenax nivalis*
The first juvenile snow buntings were observed on 10 July in Morænebakkerne, outside the census area. The first fledged juveniles were seen on 28 August – also in Morænebakkerne.

In late August, numerous flocks of juvenile snow buntings were observed in the valley. On 23 August a flock of 170 juveniles were recorded in the central part of the valley. In the following five days huge numbers of juveniles roosted in the valley. An estimated 2000 juveniles and newly moulted adults were in the valley on 26 August, with flock sizes between 13 and 60. This is by far the largest number of birds seen in these late flocks, since the beginning of the monitoring programme. Larger flocks have been seen many times before, and the largest number of birds prior to 2006, were recorded in 1999 (Caning and Rasch 2000) – another late season.

On 16 July, one bird roosted shortly on Sandøen.

3.4 Mammals

Martin Ulrich Christensen and Niels Martin Schmidt

The mammal monitoring programme was conducted by Martin Ulrich Christensen (26 May – 27 August). Additionally, Niels Martin Schmidt (26 May – 6 June and 4 July – 25 July), Jannik Hansen (6 June – 27 August), Ditte Katrine Hendrichsen (27 June – 1 August) contributed to mammal observations during the season. The station personnel and visiting researchers supplied random observations during the entire field season.

The collared lemming census area was surveyed for winter nests during 20 July – 23 August. Throughout the entire season, when weather permitted a sufficient coverage, daily musk oxen were counted from a fixed point of the research station. Counting took place between 20 and 23 hrs, and covered the coastland and mountain slopes from Zackenbergdalen in the west to Daneborg in the east. At the same time, numbers of seals on the ice in Young Sund and arctic hares on the south-east and east facing slopes of Zackenbergfjeld were censused during 26 May – 20 July and 1 July – 27 August, respectively.

The total numbers of musk oxen, including sex and age from as many individuals as possible, were censused weekly within the 40 km² musk ox census area during 7 July – 16 August. 15 known fox dens (nos. 1-10 and 12-16) within the central part of the valley were checked weekly for occupation and breeding. The only known den (no. 11) between Daneborg and Kuhnelv was checked on 20 August. The line transect Zackenberg-Store Sødal was walked 16-18 July by Niels Martin Schmidt and Martin Ulrich Christensen. The line transect from Daneborg to Zackenberg was cancelled due to impassable rivers and bad weather conditions.

Observations of other mammals than lemmings, foxes, musk oxen, and arctic hare are presented in the section "Other observations" below.

Collared lemming population

A total of 265 collared lemming (*Dicrostonyx groenlandicus*) nests from the previous winter were recorded within the 2.05 km² census area (Table 3.31). Compared to last year it represents a small increase (Fig. 3.5 and Table 3.31), and the extensive snow cover this year (see section 2.2) may have benefited the lemming population. Only one winter nest was found at the Store Sødal transect, and together with the numbers from the winter 1999/2000 it is by far the lowest number of records (Table 3.32).

In the years 1995-2005, between 0.0% and 5.0% of the lemming winter nests were depredated by stoat (Fig. 3.5), corresponding to 0.0-13.0 depredated nests per km². As in the 2005 season not a single nest was depredated by stoat this year.

The 29 fixed sampling sites for predator scats and casts were checked on 24 August (Table 3.33). In general, the numbers of scats and casts were very low, and the lack of stoat scats fits well with the lack of depredated winter lemming nests and sightings of stoats (see below).

Musk ox population

The pattern of musk oxen (*Ovibos moschatus*) occurrence in Zackenbergdalen and on the adjacent slopes nearly fits one of the patterns previously described for the previous years (e.g. Klitgaard et al. 2006), i.e. low numbers during late May and June, and increasing numbers throughout July and August (Table 3.34 and Fig. 3.6), but weekly mean observed were higher than the 1996-2005 mean (Fig. 3.6). Overall the number of musk oxen per observation in 2006 was nearly the same as in 2005 within the 40 km² census area, while it was the second highest in the entire visible area of 135 km² (Fig. 3.7). As in 2005, the number of musk oxen observed in the Zackenberg valley represents a large fraction of the total musk ox population of Wollaston Forland and A.P. Olsen Land, estimated to encompass around 500-800 animals (Boertmann and Forchhammer 1992, Rasch and Caning 2003).

Based on the average of the weekly sex and age distribution in 2006, F4+ represented the lowest proportion registered so far, while F3 represented the highest proportion of F3 (Table 3.35). Furthermore, the proportion of M2, M1, and F1 were the highest since 1998 and 1996, respectively. Consequently, the remaining sex and age classes made up larger proportions (Table 3.35).

Table 3.31. Number of collared lemming winter nests recorded within the 2.05 km² census area in Zackenbergdalen 1995-2006, together with the number of animals encountered by one person with comparable effort within the bird census area. Category 1 nests from previous winters, category 2 nests from earlier winters that have not been recorded previously.

Year	Winter nests category 1	Winter nests category 2	Animals seen
1995	285	821	-
1996	161	263	0
1997	342	109	1
1998	711	109	43
1999	305	57	9
2000	184	70	1
2001	318	22	11
2002	311	29	4
2003	96	31	1
2004	431	24	23
2005	232	154	1
2006	265	85	3

In 2006 the proportion of the different sex and age classes changed from week to week (Fig. 3.8). The proportion of M2 increased nearly every week from 3.70% in week 1 to 18.51% in week 7. In the same time F3 decreased from 18.51% to 5.33%. M4+ increased from 20.37% in week 1 to 30.48% in week 2, and then remained stable during the summer. The opposite pattern was observed for M3 that decreased from 7.41% in week 1 to 2.50% in week 2, and then remained stable (Fig. 3.8).

Five fresh musk ox carcasses were registered during the 2006 season (Table 3.36).

Arctic fox dens

In 2006, a minimum of 17 arctic fox (*Alopex lagopus*) pups (all white colour

Table 3.32. Lemming winter nests recorded along the 170 km transect Zackenberg – Store Sødal 1996-2006. Nests are recorded within 3 m on each side of the two observers. The transect Daneborg – Zackenberg was not undertaken in 2006.

Section	Distance km	Winter nests No.	No./km
Store Sødal			
1996	150	2	0.01
1997	300	11	0.07
1998	150	21	0.14
1999	130	3	0.02
2000	130	1	0.01
2001	130	13	0.10
2002	130	9	0.07
2003	130	12	0.09
2004	108	2	0.02
2005	130	2	0.02
2006	130	1	0.01
Daneborg - Zackenberg			
1997	50	22	0.44
1998	50	17	0.34
1999	40	1	0.03
2000	40	0	0.00
2001	40	24	0.60
2002	40	5	0.13
2003	40	1	0.03
2004	40	16	0.40
2005	40	22	0.55
2006	-	-	-

phase) were observed in the 15 dens checked weekly. This is the second highest number recorded so far (Table 3.37). Also, the number of fox records in the field was very much higher than generally recorded previously, except for the record number in 2004 (Table 3.38). Pups were recorded in 4 dens. However, it was estimated that only 3 families were present since one family moved back and fourth between den no. 3 and no. 4. From observations of the 15 dens, six were used regularly during the summer (nos. 1, 2, 3, 4, 10 and 12), and seven were visited irregularly (nos. 5, 6, 7, 13, 14, 15 and 16). At least three of the six regularly used dens were used for breeding (nos. 2, 3 and 12). The den (no. 11) between Daneborg and Kuhnelv was checked only once, but seemed to be used regularly (Table 3.37). The carcass of one Arctic fox was found (Table 3.38).

Arctic hare

The south-east and east facing slopes of Zackenbergfjeld were scanned by a 30× spotting scope daily from 1 July to 27 August, and the number of arctic hares (*Lepus arcticus*) was recorded. Thirty counts with good visibility were made with a mean of 13.2 arctic hares per census, a maximum of 24 on 8 August and a minimum of 5 on 4 July. This is a little higher than the record year in 2005 with a mean of 12.6 Arctic hares, but much higher than all other years (Table 3.39). The number of arctic hares observed at other sites than Zackenbergfjeld was not correspondingly high this season. Only 60 arctic hares were spotted and 28 of them were observed when counting musk oxen from a fixed point of the research station. Nevertheless, it seems that the population of arctic hares on the south-east and east facing slopes of Zackenbergfjeld remained on the same high level as in 2005.

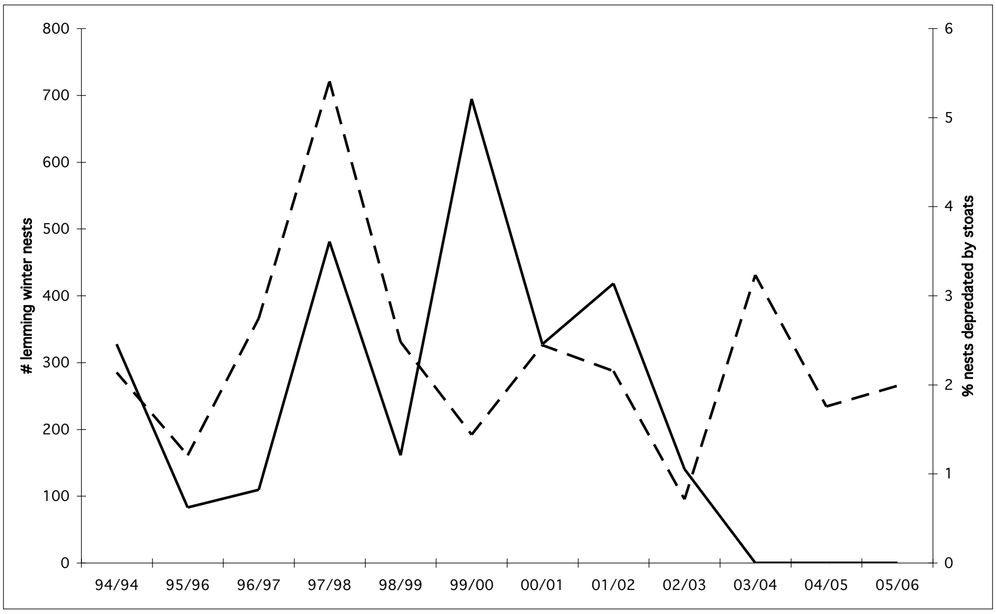


Fig. 3.5. The number of collared lemming winter nests registered in the 2.05 km^2 census area (dashed line), along with the percentage of nests taken over by stoats 1995-2006 (full line).

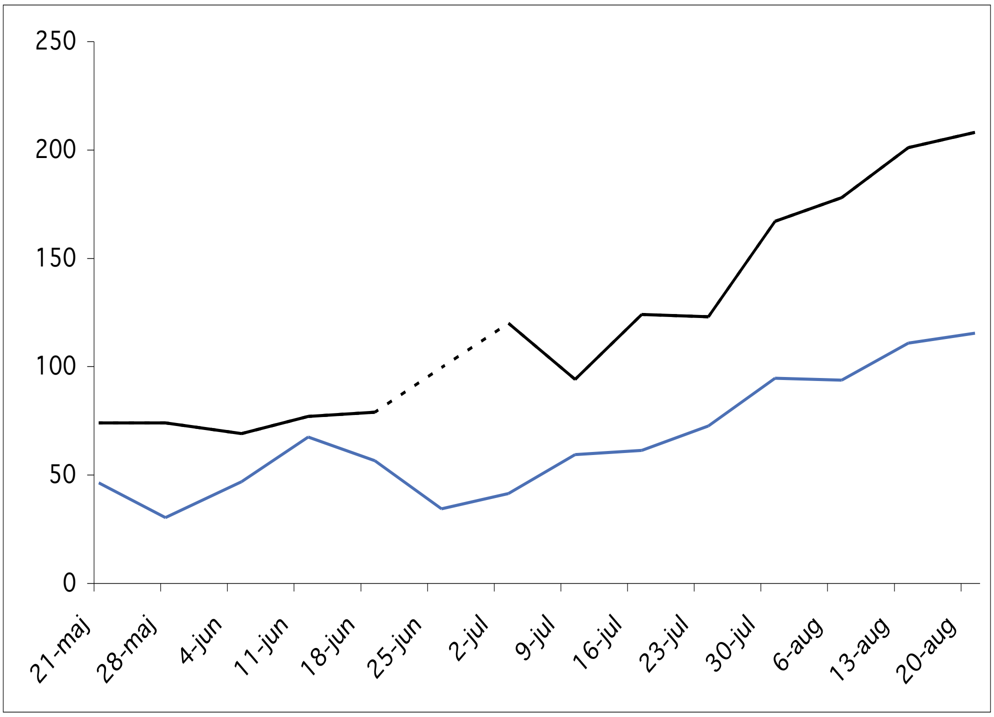


Fig. 3.6. Number of musk oxen (weekly means per day) recorded from a fixed elevated point at the research station from late May to late August 2006. Dashed line indicates interpolated values due to inclement weather. Grey line indicates the 1996-2005 mean.

Other observations

Polar bear *Ursus maritimus*

No animals or tracks were observed.

Arctic wolf *Canis lupus*

No animals were seen but tracks were observed on two occasions. An old faecal sample was found at fox den no. 4.

Stoat *Mustela erminea*

No animals or tracks were seen, and none of the 265 lemming winter nests found in the census area were depredated by stoats. During the standardised collection of scats and casts, no stoat scats were found (Table 3.33).

Year	Skua casts	Owl casts	Fox scats	Stoat scats
1997	44	0	10	1
1998	69	9	46	3
1999	31	3	22	6
2000	33	2	31	0
2001	39	2	38	3
2002	32	6	67	16
2003	16	0	20	1
2004	27	0	16	3
2005	7	6	24	0
2006	15	4	29	0

Table 3.33. Numbers of predator casts and scats collected at 29 permanent sites within the lemming monitoring census area in Zackenbergdalen. Samples represent the period from mid/late August the previous year till August in the year denoted.

Year	May	June	July	August	Total
1996		445	445	2412	3302
1997		290	1086	1432	2807
1998		522	635	1121	2278
1999		361	392	1292	2045
2000		478	898	1543	2919
2001		923	1257	1689	3868
2002		418	448	1819	2684
2003		287	638	2247	3172
2004		1311	786	3285	5381
2005	1064	2090	1353	3449	6891
2006		1523	1743	4187	7453

Table 3.34. Total number of 'musk ox days' per month, calculated as the accumulated numbers of musk oxen recorded daily within the 40 km² census area in Zackenbergdalen 1996-2006. May is not included in the total.

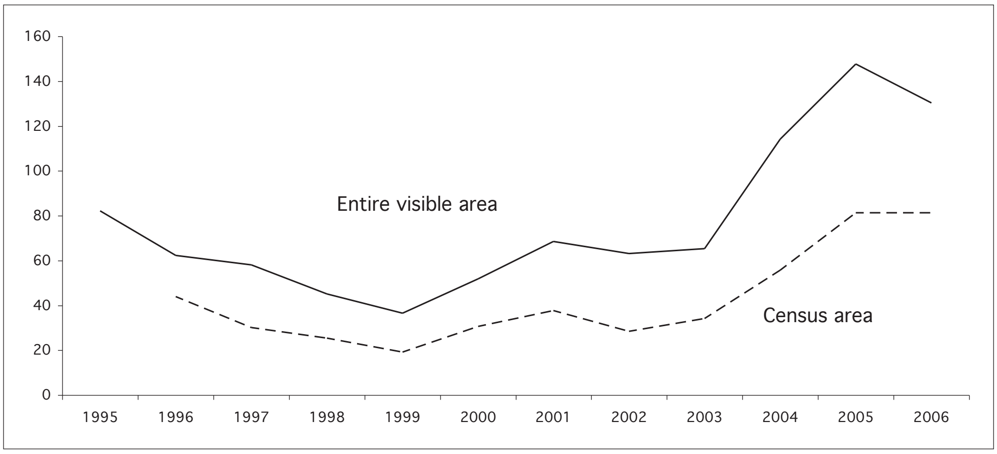


Fig. 3.7. Annual average numbers of musk oxen observed from a fixed elevated point at the research station 1995-2006 within the 40 km² census area and the entire visible area (c. 135 km²).

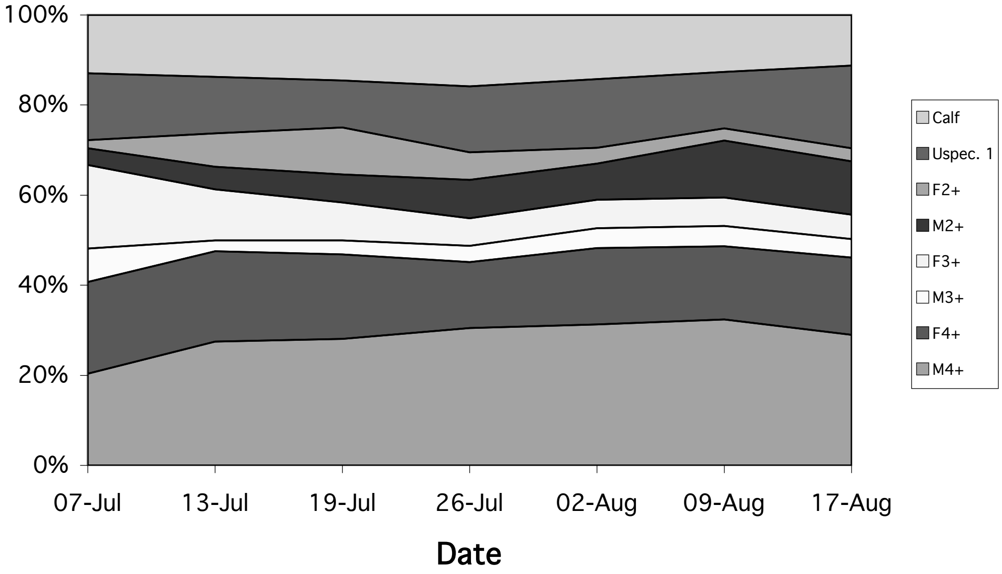


Fig. 3.8. The sex and age composition of musk oxen registered during the weekly censuses within the 40 km² census area during July and August 2006.

Walrus *Odobenus rosmarus*

Between 50 to 100 walruses use Sandøen as haul out site and feed in Young Sund, where a maximum of 34 were seen in 2006 (Nette Levermann and Anders Tøttrup, pers. comm.). However, they are only rarely seen in the shallow waters along the coast of Zackenbergdalen, and in 2006 not a single walrus was observed there.

Seals *Phoca sp.*

Different seal species haul out on the ice of Young Sund but the specific species cannot be identified during the daily censuses from the research station. Seals were recorded from 1 June until 11 July when the ice became too fragmented. A total of 21 counts were made with an average of 14 seals per census and a maximum of 22 on 6 July (Table 3.40). The average number of seals in 2006 was approximately the same as last year but markedly lower compared to the average of 22.45 seals in the years 1997 through 2005.

Narwhal *Monodon monoceros*

On 26 July, a minimum of 15 narwhales were spotted in front of the new delta in Young Sund. The day after at least 5 narwhales was seen in the same area, and they are most likely the same as seen the day before. On 8 August a minimum of 10 narwhales was observed at Daneborg on their way out of Young Sund.

3.5 Lakes

Kirsten Christoffersen and Erik Jeppesen

Sommerfuglesø and Langemandssø in Morænebakkerne were sampled three times during the period 30 July to17 August following the standard BioBasis monitoring program for lake surveys. Concomitant to the late snowmelt, both lakes melted free late in the season. Dates of 50% ice coverage for Sommerfuglesø and Langemandssø was 5 July and

Year	M4+		M3		M2		F4+		F3		F2		1M+1F		Calf		Not determined		No. of weekly
	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	counts
2006	205	29.12	29	4.12	62	8.81	123	17.47	55	7.81	34	4.83	102	14.49	94	13.35	0	0.00	7
2005	212	23.17	11	1.20	43	4.70	260	28.42	46	5.03	21	2.30	116	12.68	200	21.86	6	0.66	9
2004	122	22.22	13	2.37	5	0.91	98	17.85	28	5.10	8	1.46	32	5.83	124	22.59	119	21.68	7
2003	123	23.25	24	4.54	16	3.02	208	39.32	23	4.35	19	3.59	44	8.32	72	13.61	0	0.00	8
2002	114	19.93	20	3.50	38	6.64	205	35.84	24	4.20	43	7.52	51	8.92	77	13.46	0	0.00	8
2001	127	30.17	8	1.90	26	6.18	120	28.50	19	4.51	19	4.51	43	10.21	55	13.06	4	0.95	7
2000	109	29.54	11	2.98	2	0.54	118	31.98	15	4.07	7	1.90	31	8.40	73	19.78	3	0.81	8
1999	144	37.89	21	5.53	9	2.37	106	27.89	21	5.53	12	3.16	5	1.32	30	7.89	32	8.42	8
1998	97	29.48	22	6.69	30	9.12	97	29.48	19	5.78	27	8.21	14	4.26	22	6.69	1	0.30	8
1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1996	98	14.50	7	1.04	54	7.99	184	27.22	31	4.59	17	2.51	146	21.60	124	18.34	15	2.22	9

Table 3.35. Sex and age distribution of musk oxen within the 40 km² census area in Zackenbergdalen encountered during the weekly censuses 1996-2006. The numbers from 1997 have been omitted due to methodological differences.

	Total carcasses	4+ yrs F / M	3 yrs F / M	2 yrs F / M	1 yr F / M	Calf
1994-1995	2	0 / 1				1
1995-1996	13	7 / 1	0 / 1	0 / 2	1 / 1	
1996-1997	5	0 / 2		1 / 0	1 / 0	1
1997-1998	2	0 / 2				
1998-1999	1	0 / 1				
1999-2000	8	0 / 6	1 / 0			1
2000-2001	4	0 / 4				
2001-2002	5	1 / 2	1 / 0			1
2002-2003	3	0 / 2				1
2003-2004	2	1 / 1				
2004-2005	6	2 / 3				1
2005-2006	5	0 / 2			0 / 1	2

Table 3.36. Fresh musk ox carcasses encountered during the field seasons 1995-2006 in Zackenbergdalen. F=female, M=male.

Year	No. of known dens inside/outside	No. of dens in use inside/outside	No. of breed. dens inside/outside	Total no. of pups recorded
1995	2/0	0/0	0/0	0
1996	5/0	4/0	2/0	5W + 4D
1997	5/0	1/0	0/0	0
1998	5/0	2/0	1/0	8W
1999	7/0	3/0	0/0	0
2000	8/0	4/0	3/0	7W
2001	10/2	6/1	3/1	12W + 1D
2002	10/2	5/1	0-1/0	0
2003	11/2	8/1	3/0	17W
2004	12/2	12/2	4/1	18W
2005	14/2	6/0	0/0	0
2006	15/1	6/1	3/0	17W

Table 3.37. Numbers of known dens in use, numbers with pups and the total number of pups recorded at their maternal dens within and outside the 50 km² census area in Zackenbergdalen 1995-2006. W=white phase, D=dark phase.

10 July, respectively, which is relatively late compared to previous years (Table 3.42).

Water temperatures varied between 8.8°C and 10.8°C, with mean temperatures of 10.1°C and 9.8°C in Sommerfuglesø and Langemandssø, respectively, and thus represent a "warm" season where the average water temperatures reach 10°C. This has been the case for the last four years (Tables 3.41 and 3.42). The variations in water temperature are related to hydrological conditions (depth, residence time and inflowing melt-water) and the snow cover and depth of the entire area, water temperature being higher in years with early ice-melt, but was also influenced by the actual weather conditions. However, the water chemistry i.e., concentrations of total nitrogen and total phosphorus as well as the value for conductivity remained within the average values that have been recorded for the lakes since 1997 (Table 3.42).

Table 3.38. Total numbers of encounters with arctic fox in the field away from their dens during June-August 1996-2006.

Year	Total number of records	Total number colour phase	Number of fox carcasses
1996	34	31W + 3D	
1997	22	17W + 5D	1W + 1D
1998	24	21W + 3D	1W
1999	19	18W + 1D	2W
2000	28	28W	2W
2001	55	54W +1D	1W
2002	23	23W	0
2003	50	50W	0
2004	90	90W	0
2005	58	58W	0
2006	74	74W	1W

Year	Average ± SD	Range	Counts
1997	8.52 ± 4.98	3-21	23
1998	7.42 ± 4.50	0-18	18
1999	25.05 ± 12.32	2-61	22
2000	14.38 ± 7.00	2-28	16
2001	22.06 ± 14.22	3-57	16
2002	28.68 ± 3.82	9-48	13
2003	63.58 ± 32.09	14-126	12
2004	19.00 ± 6.40	9-30	13
2005	13.40 ± 12.82	2-48	15
2006	14.10 ± 4.54	6-22	21

Table 3.40. Numbers of seals counted during the daily censuses from 1 June until the fjord ice became too fragmented in early/mid July 1997-2006. Only counts conducted with good visibility are included.

Year	Sum	Average ± SD	Range	Counts	Others
2000	57	1.74 ± 2.9	0-11	16	67
2001	52	0.84 ± 1.52	0-6	22	72
2002	17	0.27 ± 0.73	0-4	16	19
2003	94	1.45 ± 2.82	0-13	20	42
2004	56	0.89 ± 1.7	0-3	23	135
2005	607	12.65 ± 8.59	0-30	48	150
2006	447	13.15 ± 4.46	5-24	34	32

Table 3.39. Number of arctic hares counted on the daily censuses during July and August. 'Average' is the mean number per observation day. 'Others' is the total number of arctic hares observed outside the census area.

The chlorophyll a concentrations which are a measure of the phytoplankton biomass were surprisingly low compared to most previous years. The average concentrations of 0.65 and 0.56 µg/l in Sommerfuglesø and Langemandssø, respectively, have been recorded in colder years such as 1998-2000 (Tables 3.41 and 3.42). The phytoplankton communities were as always in these lakes totally dominated by chrysophytes (Table 3.43 and 3.44), with averages of 65% and 78% of the total biovolume in Sommerfuglesø and Langemandssø, respectively. Dinophytes constituted the majority of the remaining biovolume (25% in Sommerfuglesø and 7% in Langemandssø).

The composition of the zooplankton communities were analysed from samples taken in mid-August (Table 3.45). It appeared as expected that Sommerfuglesø had a population of the cladoceran *Daphnia pulex* since this lake is without fish. The recorded density of *D. pulex* was 7 ind/l and was accompanied by two rotifers species with a combined density of 42.5 ind/l and a few juvenile copepods (copepodites and nauplii) that accounted 1.9 ind/l. In Langemandssø that has a population of Arctic char (*Salvelinus alpinus*) no daphnids were present but had instead a high density of the copepod *Cyclops abyssorum alpinus* (11.7 copepodites/l and 5.1 nauplii/l). There was also a substantial number of two rotifer species (*Polyarthra sp.* and *Keratella quadrata*).

Table 3.41. Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July and August 2006.

Lake Date	SS 30.7	SS 8.8	SS 17.8	LS 30.7	LS 8.8	LS 17.8
Ice cover (%)	0	0	0	0	0	0
Temperature (°C)	10.8	8.8	10.6	10.4	8.9	10.0
pH	6.29	6.1	6.26	5.88	6.9	6.25
Conductivity (µS/cm)	8	15	10	5	5	6
Chlorophyll a (µg/l)	0.56	0.73	0.75	0.74	0.62	0.33
Total nitrogen (µg/l)	240	240	400	230	150	230
Total phosphorous (µg/l)	9	5	9.00	5	8	5

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Date of 50% ice cover	ND	11.7	18.7	25.6	2.7	3.7	24.6	24.6	18.6	5.7	ND	23.7	21.7	30.6	8.7	6.7	2.7	26.6	22.6	10.7
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	11.0	8.7	9.8	10.1	6.8	6.4	4.0	9.5	8.4	8.1	11.1	9.1	10.5	9.8
pH	6.5	7.4	6.7	5.8	6.6	6.0	6.5	6.3	6.0	6.2	6.5	7.0	6.3	5.5	6.4	5.5	6.1	6.1	6	6.3
Conductivity (µS/cm)	15	13	10	18	18	8	12	15	22	11	8	9	7	9	8	6	6	8	14	5
Chlorophyll a (µg/l)	0.84	0.24	0.41	0.76	0.67	1.27	1.84	1.62	1.59	0.65	1.04	0.32	0.38	0.90	1.46	2.72	3.14	0.98	1.62	0.56
Total nitrogen (µg/l)	ND	130	210	510	350	338	277	267	263	293	ND	80	120	290	340	387	237	230	247	203
Total phosphorous (µg/l)	4	9	11	10	19	11	11	7	9	8	8	7	7	11	20	13	10	11	11	6

Table 3.42. Average physico-chemical variables in Sommerfuglesø (SS) and Langemandssø (LS) in 1999-2006 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data.

Lake	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**
Date	**30.7**	**8.8**	**17.8**	**30.7**	**8.8**	**17.8**
Nostocophyceae	0.000	0.000	0.000	0.000	0.000	0.000
Dinophyceae	0.024	0.056	0.123	0.089	0.040	0.076
Chrysophyceae	0.169	0.123	0.143	0.069	0.252	0.634
Diatomophyceae	0.013	0.005	0.003	0.000	0.017	0.010
Chlorophyceae	0.005	0.003	0.003	0.008	0.006	0.011
Others	0.000	0.000	0.000	0.000	0.000	0.000
Total	**0.211**	**0.187**	**0.272**	**0.166**	**0.315**	**0.731**

Table 3.43. Biovolume (mm^3/l) of phytoplankton species in Sommerfuglesø and Langemandssø during July-August 2006.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Year	**1998**	**1999**	**2001**	**2002**	**2003**	**2005**	**2006**	**1997**	**1998**	**1999**	**2001**	**2002**	**2003**	**2005**	**2006**
Nostocophyceae	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.185	0.068	0.291	0.185	0.305	0.040	0.156	0.123	0.030	0.068
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.554	0.145	0.066	0.187	0.048	0.592	0.377	0.358	0.296	0.318
Diatomophyceae	0.002	0.000	0.001	0.000	0.000	0.000	0.007	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.009
Chlorophyceae	0.005	0.002	0.000	0.000	0.002	0.009	0.004	0.016	0.000	0.002	0.002	0.000	0.003	0.019	0.008
Others	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**0.063**	**0.147**	**0.377**	**0.073**	**0.266**	**0.749**	**0.223**	**0.375**	**0.372**	**0.354**	**0.637**	**0.533**	**0.484**	**0.345**	**0.404**

Table 3.44. Average biovolume (mm^3/l) of phytoplankton species in Sommerfuglesø and Langemandssø from 1997 to 2006 (except for 2000 and 2004).

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Cladocera																				
Daphnia pulex	0.3	10.5	0.3	6.7	8.2	6.8	7.7	0.7	6.4	7.07	0	0	0	0	0	0	0.1	0	0	0
Macrothrix hirsuiticornis	0.1	0	0	0	0	0	0	0	0.07	0	0	0	0.2	0	0	0	0	0	0	0
Chydorus sphaericus	0.05	0	0	0	0.06	0	0	0	0.13	0	0	0.1	0	0.5	0.1	0.07	0	0	0.13	0.07
Copepoda																				
Cyclops abyssorum alpinus (adult+copepodites)	0.8	0.5	0.5	0.3	0.5	0.2	0.9	0.3	0.07	0.27	3.3	2.9	4.1	22.0	13.4	6.8	8.6	4.9	5.8	11.74
Nauplii	5.7	1.3	6.5	1.1	1.4	2.3	0.3	0.3	0.2	1.67	5.2	3.8	6.4	3.1	4.5	4.5	4.2	0	2.20	5.13
Rotifera																				
Polyarthra dolicopthera	171	90	185	97	74	11	0.5	1.87	7.67	42.2	316	330	274	168	248	22	78	71	99	181.33
Keratella quadrata group	4.5	3.0	17	0	0	0.4	0.1	0	0	0.33	4.5	28	34	0	0	0.3	0	1.3	0	41.33
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euchlanis sp.	0	0	0	0	0	0	0	0	0.33	0.07	0	0	0	0	0	0	0	0	0	0

Table 3.45. Density (no/l) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) in mid-August 1997-2006.

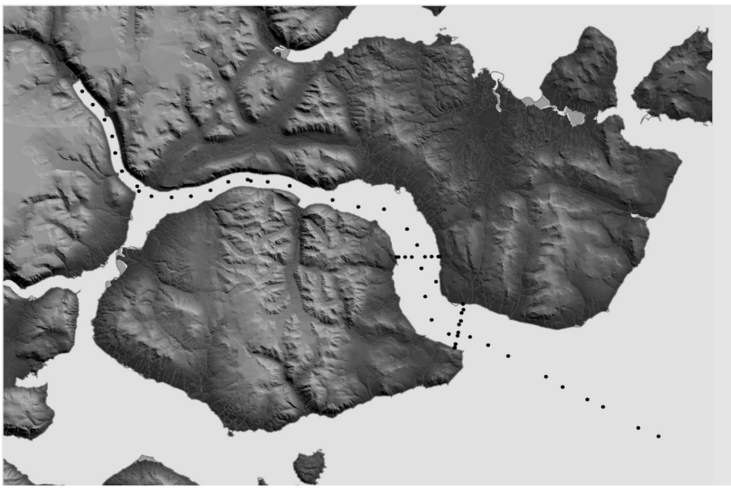
4 Zackenberg Basic
The MarineBasis Programme

Søren Rysgaard, Mikael K. Sejr, Morten Frederiksen, Kristine Arendt and Egon R. Frandsen

This is the report from the 4th year of the MarineBasis monitoring programme in the Young Sund-Tyrolerfjord system. The aim of the programme is to detect possible changes in a high-arctic marine ecosystem due to climate variability and change. This is accomplished by combining an intense summer field campaign with deployment of automated moorings supplying recordings throughout the year. Physical, chemical and biological parameters are measured in the main research area, Young Sund, but also in Tyrolerfjord and outside the East Greenland Shelf when weather conditions allow it.

The overall design of the sampling programme is a combination of stations sampled once every summer, a sampling station sampled frequently every summer and a mooring system deployed in August and retrieved one year later. Density and diversity of benthic fauna were analysed from digital images recorded along 3 transects perpendicular to the shoreline from 20-60 m water depth. The dominant species were identified and counted. Hydrographic measurements (pressure, salinity, temperature, fluorescence, turbidity) were performed along a longitudinal transect from the innermost part of Tyrolerfjord to about 40 km off the mouth of the fjord system on the East Greenland Shelf at intervals of 5-10 km between CTD casts (Fig. 4.1). The same measurements were performed along 2 transects across Young Sund at intervals of 1-2 km between CTD casts (Fig. 4.2).

Fig. 4.1. Map of the sampling area. The dots represent the hydrographic sampling stations from the innermost Tyrolerfjord on the left to the East Greenland Shelf on the right.



At the frequently visited station the following parameters were measured roughly every second day: light attenuation (PAR), vertical profiles of salinity, temperature and fluorescence, and water was sampled from 9 depths and filtered for Chlorophyll a (Chl. a) determination. In addition, 3 times during the 3-week sampling period, samples were taken for vertical profiles of UV-B absorption, $NO_3^- + NO_2^-$, PO_4^{3-}, NH_4^+, SiO_4, dissolved inorganic carbon (DIC) and total alkalinity (TA) and vertical hauls were made from bottom to top with plankton nets for zooplankton and phytoplankton determination. At the seafloor sulphate reduction and sediment-water fluxes of O_2, DIC and nutrients were measured once at a water depth of 60 m. In addition, the vertical concentration profile of O_2 in the sediment was recorded.

The mooring system launched in 2005 was retrieved in 2006 and replaced with a new system this year. The sediment mooring system was deployed at a depth of ~80 m (74°18.93′N, 20°16.70′W) and consisted of one automatic sediment trap at a depth of 60 m and 2 SBE 37-SM probes at 37 and 63 m depth deployed for a year. In addition, two summer moorings equipped with SBE 37-SM probes were placed at 1 m and 22 m depth during August 2006.

Daily visits to the island Sandøen were made throughout the field campaign. The number of walruses was counted from a Zodiac RIB at a distance of ca. 100 m in order not to disturb the animals. More details on walruses are presented by Levermann et al. (section 5.9). Finally, in connection with the military patrol SIRIUS' annual catch of arctic char, 15 individuals were frozen and the tissue will serve as a data bank of contaminants, isotopic composition etc. for future studies.

In combination with the monitoring activity of the MarineBasic programme, we made additional research investigations of CO_2 conditions in surface waters and determined the flux rate between the atmosphere and water column along and across Young Sund. Furthermore, additional sampling for zooplankton was made to compare copepod grazing in the high Arctic with sub Arctic systems. Along with our monitoring and research activities, new housing facilities for our sampling and laboratory equipment as well as boats were built in Daneborg. We greatly acknowledge the financial support from the Aage V. Jensen Charity Foundation covering the expenses for these facilities.

4.1 Sea ice

The autonomous camera system established in 2004 provided images of the ice formation and melting of sea ice in the outer part of Young Sund (Fig. 4.3). The pictures were used to estimate when fast ice was established in autumn 2005 and when it broke up in the summer thaw of 2006. The dates of ice formation and ice melt were confirmed by SIRIUS. During the open-water period in 2006 very little drift ice appeared in the fjord. Personnel from SIRIUS continued their measurements of sea ice and snow thickness at 74°18.59´N, 20°15.04W during 2005-2006. Compared to previous years, sea ice thickness was comparable, whereas a thicker snow cover was observed in 2006 compared with especially 2003 and 2004 (Fig. 4.4, Table 4.1).

Based on the dates of ice formation and ice break-up the annual ice-free period could be estimated. The summer of 2006 represents a return to "normal" ice conditions after a period of five years where the open-water period increased considerably to a maximum of 128 days in 2003 compared to an average of approximately 80 days from 1950 to 1995 (Fig. 4.5). The observed decrease in open-water conditions during 2006 may be a result of an unusually large amount of sea ice exported through the Fram Strait due to an exceptional break-up of sea ice north of Greenland and Canada. This large amount of pack ice outside Young Sund thus delayed the sea ice export from the fjord to the Greenland Sea in 2006.

	2003	2004	2005	2006
Ice thickness (cm)	120	150	125	132
Snow thickness (cm)	20	32	85	95
Days with open water	128	116	98	75

Table 4.1. Summary of sea ice and snow conditions in Young Sund

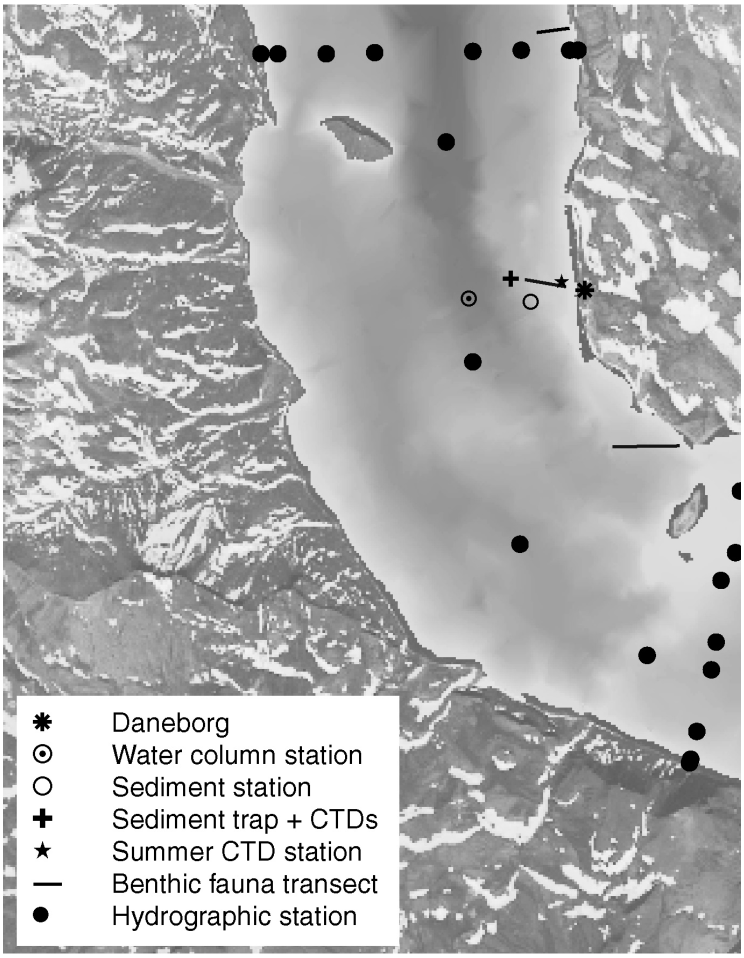


Fig. 4.2. Map showing the sampling stations in the outer part of the Young Sund in more detail.

4.2 Water column

Continuous data

Continuous data on temperature, salinity and density were obtained at two depths at the same position as that of the sediment trap (74°18.930´N, 20°16.697´W). The equipment was deployed on August 15 2005 and retrieved after one year. Data are presented in Fig. 4.6. The instrument at 63 m displayed lower variability in water temperature and salinity during 2005 as compared with the instrument at 37 m depth. Values of both salinity and temperature at 37 m and 63 m converge at the end of 2006. Two autonomous loggers were also deployed for a shorter period in August 2006. One was placed near the island Basalt Ø (74°19.85´N, 20°22.03´W) to monitor surface (1 m) variability in salinity and temperature. During the two-week period from August 1 to August 16 the range in temperature was 9°C and that of salinity 12 psu units. A logger was also deployed at 22 m depth off Daneborg (74°18.87´N, 20°14.78´W). Increased variability in temperature and salinity was observed during the middle of the period, which corresponded with increased salinity and decreased temperature in the surface water at Basalt Ø (Fig. 4.7).

The sediment trap was retrieved late August. Unfortunately, most of the sample cups collected during spring were filled with copepods, which makes it impossible to quantify accurately the vertical export of organic carbon during this year's deployment. Presumably, the copepods had been trapped during their migration from deeper waters. Our sediment trap only prevents larger animals from entering the trap. At present, no techniques are available to prevent occasional import of active swimming copepods without affecting the sedimentation measurement. However, this is a rare event, and we only know of one similar incident from Arctic Canada (Martin Fortier pers. Communication).

Fig. 4.3. Sea ice conditions during 2005-2006 in Young Sound as documented from Daneborg.

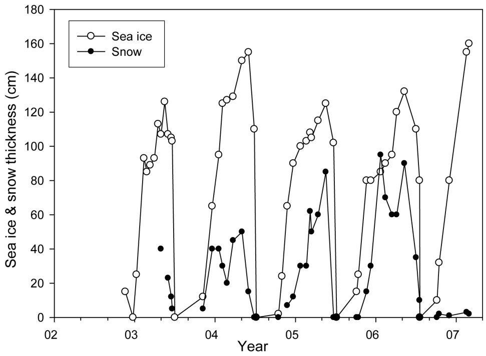


Fig. 4.4. Snow and sea ice thickness in the outer part of Young Sund.

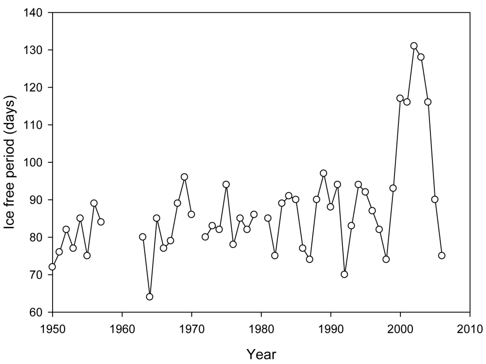


Fig. 4.5. Duration of ice-free period in summer (days) in the outer part of Young Sund

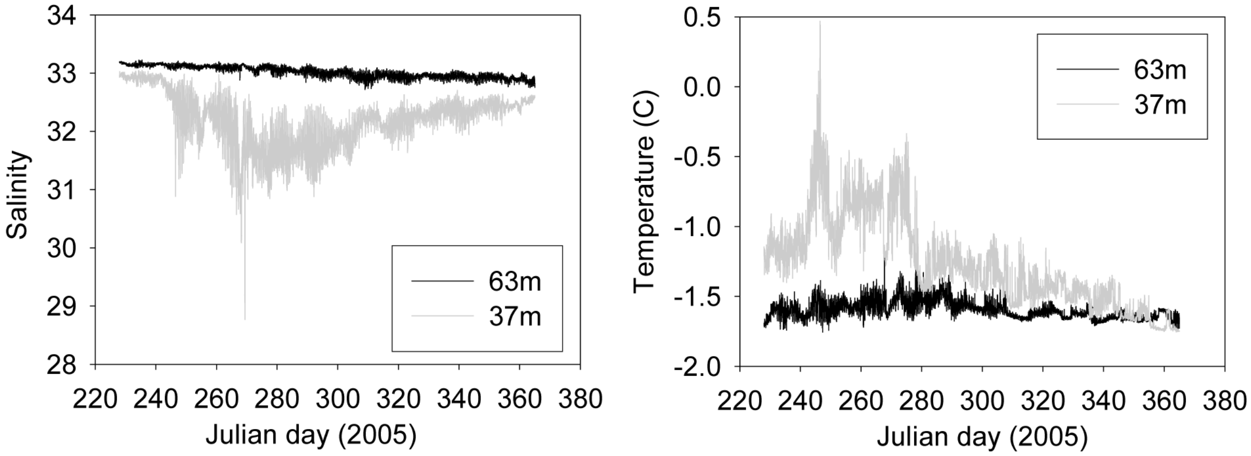


Fig. 4.6. Time series of salinity and temperature from two depths (37m and 63m) in Young Sund. The mooring was deployed on 15 August, 2005.

Distribution of temperature, salinity, density and chlorophyll in Young Sund

Distribution of temperature, salinity, density and fluorescence was obtained at 23 stations on August 9 and 10 along a transect from the inner part of Tyrolerfjord through Young Sund onto the East Greenland Shelf (Fig. 4.8). Fluorescence was converted to Chl. a concentrations based on water samples collected at the hydrographic station (see below). As observed in previous years, maximum Chl. a values were observed at the entrance to Young Sund just outside the sill. Maximum concentration was 2.5 µg l^{-1}. Due to freshwater input from land decreasing surface-water salinity was observed towards Tyrolerfjord. The thickness of the low-saline surface water gradually decreased towards the East Greenland Shelf. In the Greenland Sea water with high salinity (>34 psu) and temperature (>1°C) was observed at 200-300 m depth. The temporal variability of the upper 150 m of the water column was investigated further through a series of vertical profiles at the standard hydrographic station (74°18.58´N, 20°1811´W) during the stay in August (Fig. 4.9). A subsurface maximum of Chl. a was observed around 30 m depth at the beginning of the period, after which it was reduced due to a combination of grazing and mixing of the surface waters by high wind conditions around 6August. The high temperature and low salinity of the surface water were gradually reestablished at the end of the study period.

Cross-sections of vertical profiles in Young Sund were performed along two transects; one near Basalt Ø and one near

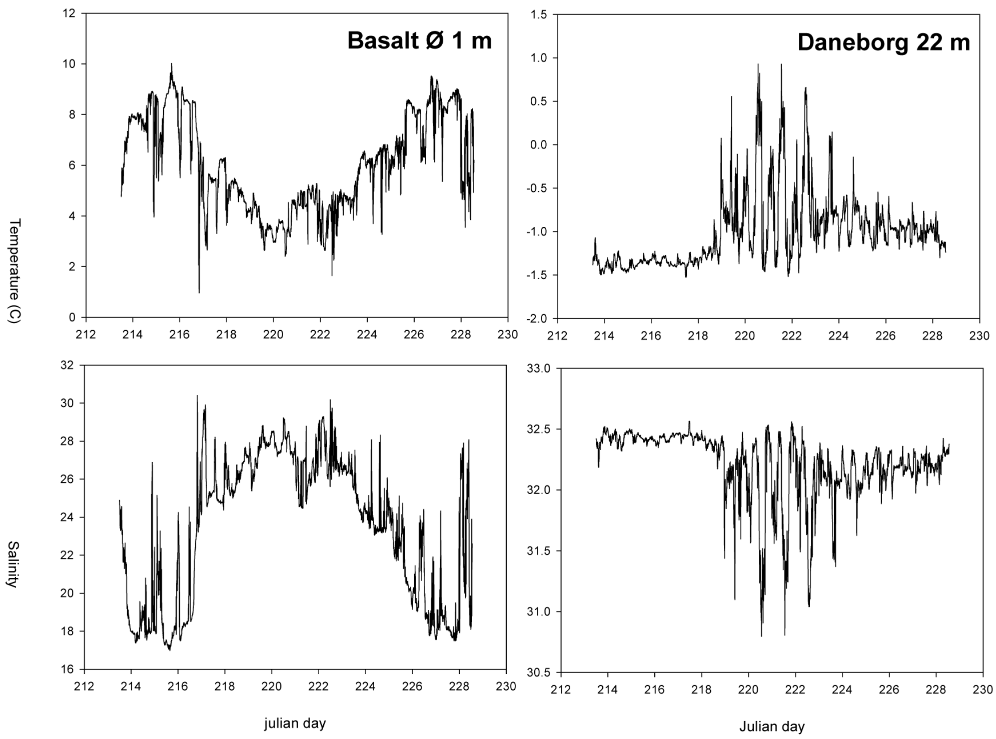


Fig. 4.7. Data from the mooring systems deployed from 1 August to 16 August, 2006 at Basalt Ø (1 m depth) and off Daneborg (22 m depth). Time series of temperature (upper panels) and salinity (lower panels) are shown.

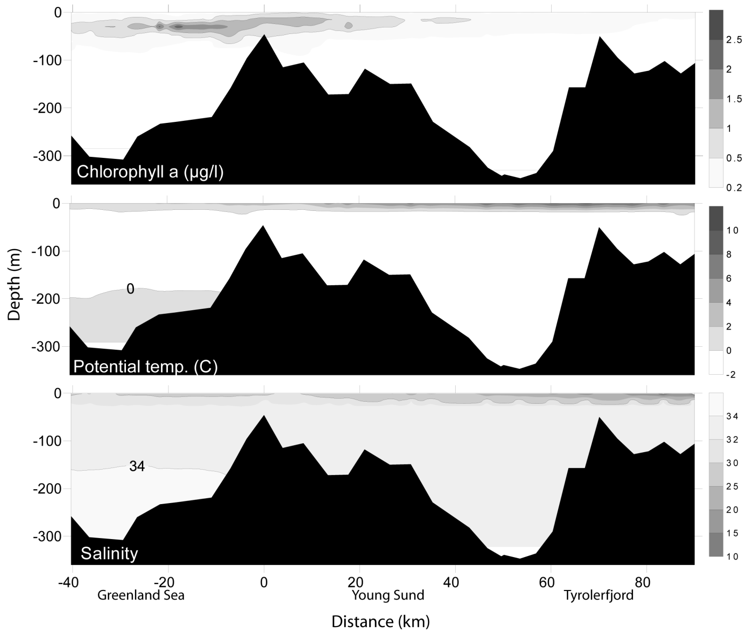


Fig. 4.8. Chlorophyll a, temperature and salinity in the Young Sund – Tyrolerfjord system in August 2006. Vertical lines represent sampling points.

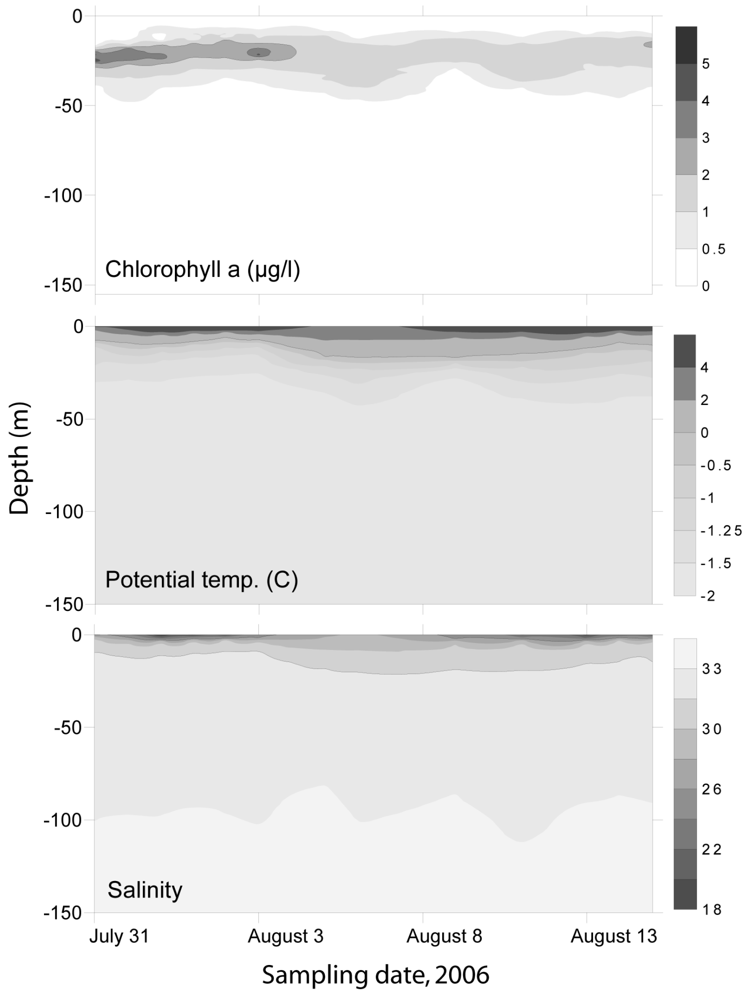


Fig. 4.9. Chlorophyll a, temperature and salinity during August 2006 at the water column station in Young Sund.

Sandøen. The transect near Basalt Ø is depicted in Fig. 4.10 and shows that Chl. a levels may vary across the fjord, possibly due to wind-induced upwelling as observed in previous studies of the fjord (Bendtsen et al. 2007). Furthermore, the salinity distribution across the fjord shows a deepening of the shallow low-saline surface layer near the coast of Clavering Ø, i.e. the coast located to the right of the outflowing surface water.

The physical conditions during 2006 at two stations, one at the East Greenland Shelf and one in Young Sund, is compared with previous years in Fig. 4.11. The most notable difference in 2006 compared with the previous years was observed at station GH_07 on the East Greenland Shelf where the presence of the warmer water of Atlantic origin was much more pronounced in 2006. Hydrographic conditions from 2003-2006 are summarized in Table 4.2. Overall, the standard station in Young Sund was colder and more saline in the upper 50 m as compared with previous years.

Nutrients, dissolved inorganic carbon (DIC) and total alkalinity (TA)

Nutrient, DIC and TA concentrations in the water column of the location 74°18.58′N, 20°18.00′W were measured on three occasions (1, 8 and 15 August, 2006). The nitrate concentration was very low in the surface water due to phytoplankton uptake and dilution by melt water, and increased with depth to 5 µM (Fig. 4.12). Phosphate was detectable in the surface water and concentrations increased to 0.4-0.8 µM in the bottom water. Silicate concentration profiles were different from those of nitrate and phosphate and showed a maximum at the surface followed by very low concentrations at 10-30 m depth and an increase towards the bottom. This shows that silicate is introduced to the fjord via melt water from the rivers. Silicate concentrations were very low in the upper 45-m photic zone and strongly limited phytoplankton production (Table 4.2).

Dissolved inorganic carbon (DIC) ranged from 1,763 µM in the upper 0-5 m of the water column to an average of 2191 µM in the bottom water of Young Sund (Fig. 4.13, Table 4.2). Total alkalinity (TA) followed the same vertical trend as DIC and ranged from 2002 to 2,441 µM in the water column. The concentration profiles of DIC and TA showed similar patterns

0-5 m water depth	2003	2004	2005	2006
Potential temp. (°C)	5.570 ± 0.175	5.515 ± 0.158	4.612 ± 0.077	3.59 ± 0.46
Salinity	28.10 ± 0.230	26.02 ± 0.247	27.42 ± 0.089	27.63 ± 0.77
Chlorophyll a (μg L^{-1})	0.727 ± 0.069	0.060 ± 0.004	0.945 ± 0.239	0.29 ± 0.08
DIC (μM)	1806.2 ± 60.4	1769.0 ± 46.5	1829.5 ± 11.5	1763 ± 58.8
TA (μM)	1929.5 ± 65.8	1867.5 ± 52.5	2066.6 ± 11.1	2002 ± 67.3
pCO$_2$ (μatm)*	302.2 ± 32.6	197.1 ± 10.1	154.8 ± 9.0	122.1 ± 4.5
NO_3^- (μM)	0.00 ± 0.04	0.16 ± 0.05	0.04 ± 0.08	0.12 ± 0.07
PO_4^{3-} (μM)	0.25 ± 0.01	0.58 ± 0.17	0.20 ± 0.01	0.56 ± 0.20
SiO_4 (μM)	2.41 ± 0.30	2.51 ± 0.59	1.85 ± 0.11	1.17 ± 0.85
0-45 m water depth	**2003**	**2004**	**2005**	**2006**
Potential temp. (°C)	2.564 ± 0.203	0.708 ± 0.095	0.998 ± 0.109	-0.32 ± 0.15
Salinity	30.44 ± 0.168	31.16 ± 0.104	31.02 ± 0.105	31.58 ± 0.15
Chlorophyll a (μg L^{-1})	0.498 ± 0.032	0.407 ± 0.021	1.465 ± 0.292	1.14 ± 0.22
DIC (μM)	2000.6 ± 40.4	1986.3 ± 3.6	2001.6 ± 17.6	2007.5 ± 26.3
TA (μM)	2146.0 ± 44.9	2175.5 ± 31.2	2263.8 ± 19.5	2274.3 ± 29.0
NO_3^- (μM)	0.83 ± 0.27	0.46 ± 0.15	0.08 ± 0.04	0.27 ± 0.14
PO_4^{3-} (μM)	0.34 ± 0.03	0.62 ± 0.08	0.24 ± 0.01	0.34 ± 0.04
SiO_4 (μM)	2.20 ± 0.2	1.45 ± 0.27	1.25 ± 0.09	0.05 ± 0.03
45-150 m water depth	**2003**	**2004**	**2005**	**2006**
Potential temp. (°C)	-1.65 ± 0.004	-1.65 ± 0.001	-1.72 ± 0.002	-1.68 ± 0.01
Salinity	32.93 ± 0.002	33.09 ± 0.001	33.21 ± 0.001	32.97 ± 0.01
Chlorophyll a (μg L^{-1})	0.257 ± 0.011	0.117 ± 0.004	1.040 ± 0.257	0.33 ± 0.14
DIC (μM)	2181.1± 7.9	2172.4 ± 0.40	2188.9 ± 3.2	2190.9 ± 3.2
TA (μM)	2318.8 ± 1.7	2347.6 ± 5.0	2450.5 ± 4.7	2440.9 ± 3.5
NO_3^- (μM)	3.95 ± 0.15	4.64 ± 0.14	3.15 ± 0.18	3.91 ± 0.35
PO_4^{3-} (μM)	0.58 ± 0.01	0.88 ± 0.11	0.50 ± 0.01	0.47 ± 0.06
SiO_4 (μM)	4.22 ± 0.27	4.48 ± 0.11	3.99 ± 0.26	4.63 ± 1.23

*Mean of surface layer (0-1 m)

Table 4.2. Summary of hydrographic conditions in Young Sund. Mean values of depth profiles sampled throughout August. ± represents Standard Error (SE) of the mean.

with stable high concentrations in the bottom waters and lower levels in the surface layers, probably due to consumption by primary producers and dilution by melt water. Atmospheric pCO$_2$ levels were significantly higher than pCO$_2$ levels in the surface water on all sampling dates showing that the CO_2 flux was directed from the atmosphere into the water column of Young Sund. This year's pCO$_2$ level of 122 μatm was the lowest observed during the monitoring program. In Table 4.2 the mean hydrographic conditions at the locality in the outer part of Young Sund are given for the first 4 years of the MarineBasic program.

Light UV-B attenuation

On seven occasions during August the light attenuation coefficient was estimated from vertical profiles in the water column. The average attenuation coefficient was slightly higher compared with previous years (Table 4.3). Water samples were also collected for estimation of the attenuation of UV-B, which was also slightly higher compared with previous years.

Phytoplankton and zooplankton

Vertical net hauls for phytoplankton was performed from 0-50 m using a 25-μm mesh net on three occasions during August (1, 8 and 15 August) at the hydrographic station. During August, little change in composition of the abundant species was observed (Table 4.4). Compared with 2005, the most notable difference is the virtual absence of *Gymnodinium sp*. from samples collected in 2006. This species constituted 30-40% of all cells in samples collected in 2005. For the zooplankton, only copepod data are shown (Table 4.5). As in the case of phytoplankton, the general species composition is relatively stable during August but abundance increases during the study period.

	2003	2004	2005	2006
PAR attenuation coeff. (m^{-1})	0.117 ± 0.007 (8)	0.136 ± 0.004 (8)	0.110 ± 0.009 (4)	0.173 ± 0.004 (7)
UV-B attenuation coeff. (m^{-1})	1.27 ± 0.05 (8)	1.43 ± 0.23 (8)	1.32 ± 0.12 (4)	1.62 ± 0.22 (4)

Table 4.3. Attenuation coefficients in the water column of Young Sund. Mean ± SE (n)

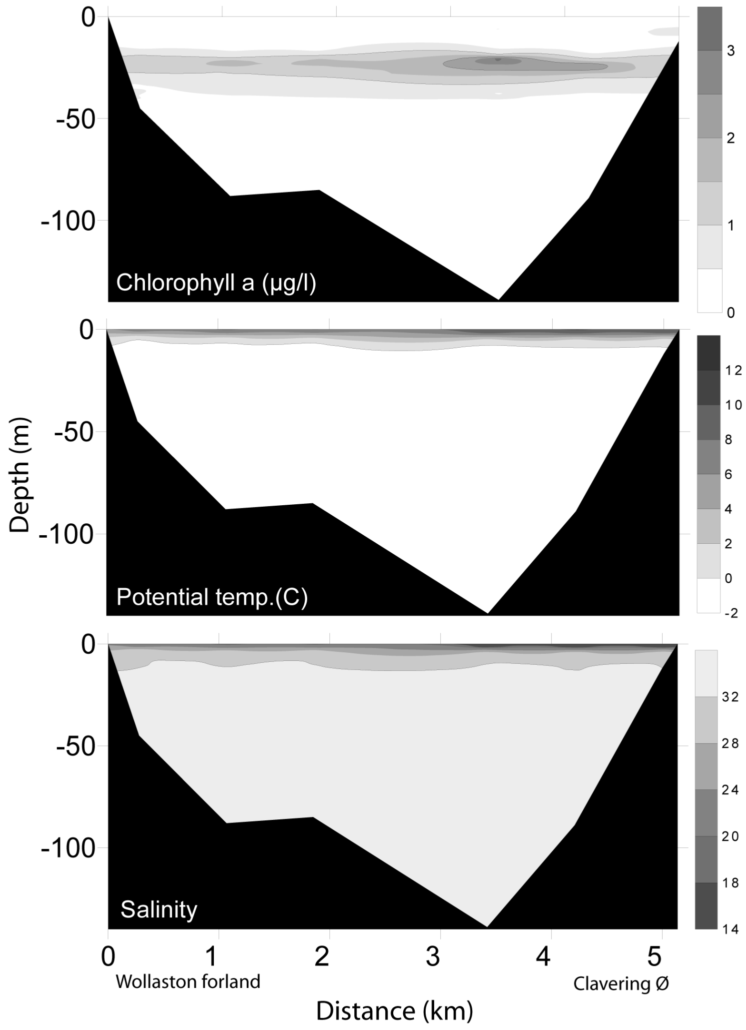


Fig. 4.10. Chlorophyll a, temperature and salinity across Young Sund, near Basalt Ø in August 2006.

An interesting trend has been observed in the relative abundance of the two Calanus species *C. hyperboreus* and *C. finmarchicus*. The ratio between *C. hyperboreus* and *C. finmarchicus* was 56:1 in 2003, 11:1 in 2004, 3:1 in 2005 and 0.8:1 in 2006. This is interesting because *C. hyperboreus* is a typical arctic species, whereas *C. finmarchicus* is generallly found in warmer Atlantic water. The shift in relative abundance between these two species could be an indication of increasing exchange with Atlantic water found in the East Greenland Current over the East Greenland continental slope more than 100 km away from the mouth of the fjord system.

4.3 Sediment

Sediment-water exchange rates of oxygen, DIC and nutrients, oxygen conditions and sulphate reduction

The organic matter reaching the sediment from the water column undergoes degradation within the sediment, a process also known as mineralization. This occurs via a number of steps involving several different electron acceptors, or oxidants. In the surface layer, O_2 serves as electron acceptor and below the oxic zone SO_4^{2-} is the dominant electron acceptor. In the anoxic zone, oxidised Fe and Mn and NO_3^- may act as electron acceptors as well. When either oxidised metals or SO_4^{2-} oxidise the organic matter, reduced species are formed, and subsequent re-oxidation of these species leads to oxygen consumption. The nutrients incorporated in the organic matter undergoing degradation are released and may bind to the sediment particles, participate in reactions in the sediment or be released to the overlying water. The sediment processes were measured in intact sediment cores sampled at a water depth of 60 m (74°18.58'N, 20°15.74'W) on 8 August 2006.

Of the organic carbon reaching the sediment surface 3.217 mmol C m^{-2} d^{-1} was returned to the water column as dissolved inorganic carbon (DIC) in 2006 (Table 4.6). The O_2 consumption by the sediment of 3203 mmol m^{-2} d^{-1} was similar to the DIC efflux. The specific O_2 consumption was highest in the upper

Table 4.4. Phytoplankton diversity during August 2006. The ten most abundant species are listed together with their relative accumulated proportion of total cell count.

	1 August 2006		8 August 2006		15 August 2006	
No. species	17 ± 1.53		19.67 ± 1.45		16.0 ± 1.0	
Diversity	0.76 ± 0.23		1.47 ± 0.08		1.78 ± 0.12	
Equitability	0.23 ± 0.08		0.49 ± 0.03		0.64 ± 0.03	
Dominant species	*Chaetoceros socialis*	69	*Dinobrion balticum*	53	*Chaetoceros wighamii*	34
	Chaetoceros wighamii	85	*Chaetoceros wighamii*	79	*Chaetoceros socialis*	61
	Fragilariopsis cylindrus	91	*Eucampia groenlandica*	84	*Eucampia groenlandica*	72
	Achnanthes taeniata	94	*Attheya septentrionalis*	87	*Thalassiosira antarctica*	79
	Fragilariopsis oceanica	95	*Fragilariopsis cylindrus*	90	*Fragilariopsis cylindrus*	86
	Attheya septentrionalis	97	*Navicula septentrionalis*	92	*Chaetoceros eibenii*	88
	Eucampia groenlandica	97	*Pseudonitzschia delicatissima*	93	*Attheya septentrionalis*	91
	Thalassiosira nordenskioeldii	98	*Thalassiosira nordenskioeldii*	95	*Chaetoceros decipiens*	94
	Thalassiosira antarctica	99	*Thalassiosira antarctica*	96	*Pseudonitzschia delicatissima*	95
	Attheya longicornis	99	*Chaetoceros eibenii*	97	*Thalassiosira nordenskioeldii*	96

Table 4.5. Composition of the copepod fauna in August 2006 in Young Sund at 0-150 m depth.

		1 August Mean (No m^{-2})	SE (n=3)	8 August Mean (No m^{-2})	SE (n=3)	15 August Mean (No m^{-2})	SE (n=3)
Pseudocalanus spp.	**female**	128.0	96.0	204.0	153.0	36.0	27.0
	male	0.0	0.0	32.0	0.0	0.0	0.0
	C V	112.0	99.9	400.0	356.9	340.0	303.3
	C IV	69.3	89.1	496.0	637.3	416.0	534.5
	C III	101.3	97.3	400.0	384.2	436.0	418.8
	C II	288.0	146.6	616.0	313.7	872.0	444.0
	C I	96.0	146.6	408.0	623.2	656.0	1002.1
	npl	240.0	360.3	544.0	816.6	1152.0	1729.3
	eggs	64.0	192.0	176.0	528.0	0.0	0.0
Oithona spp.	**female**	1578.7	1442.5	636.0	581.1	540.0	493.4
	male	394.7	566.1	268.0	384.4	24.0	34.4
	C V	1141.3	1477.2	928.0	1201.1	972.0	1258.0
	C IV	661.3	610.5	508.0	469.0	648.0	598.2
	C III	362.7	139.5	168.0	64.6	768.0	295.4
	C II	309.3	305.3	176.0	173.7	516.0	509.2
	C I	192.0	199.8	8.0	8.3	0.0	0.0
	npl	117.3	178.2	32.0	48.6	64.0	97.2
	egg sacks	85.3	160.0	8.0	15.0	64.0	120.0
Calanus	**npl**	1152.0	674.3	1364.0	798.4	3428.0	2006.5
	eggs	448.0	805.1	648.0	1164.5	808.0	1452.1
Calanus hyperboreus	**female**	10.7	16.0	12.0	18.0	8.0	12.0
	C V	10.7	16.0	44.0	66.0	24.0	36.0
	C IV	98.7	92.3	724.0	677.0	584.0	546.1
	C III	122.7	128.0	1196.0	1248.0	1036.0	1081.0
	C II	176.0	99.9	1120.0	635.9	756.0	429.2
	C I	5.3	16.0	384.0	1152.0	352.0	1056.0
Calanus finmarchicus	**female**	90.7	89.1	112.0	110.0	52.0	51.1
	male	0.0	0.0	0.0	0.0	4.0	0.0
	C V	229.3	84.7	424.0	156.5	448.0	165.4
	C IV	144.0	73.3	416.0	211.8	212.0	107.9
	C III	96.0	120.8	492.0	619.1	300.0	377.5
	C II	224.0	99.9	1080.0	481.8	1384.0	617.4
	C I	122.7	57.7	680.0	319.8	1116.0	524.8
Calanus glacialis	**female**	2.7	8.0	40.0	120.0	4.0	12.0
	C V	66.7	56.0	324.0	272.2	64.0	53.8
	C IV	0.0	0.0	0.0	0.0	0.0	0.0
Oncea	**female**	298.7	115.4	120.0	46.4	40.0	15.5
	male	21.3	64.0	0.0	0.0	64.0	192.0
	C	501.3	532.6	352.0	373.9	192.0	204.0
Microcalanus	**female**	384.0	308.6	60.0	48.2	16.0	12.9
	male	266.7	305.3	8.0	9.2	8.0	9.2
	C	1632.0	1398.9	1096.0	939.4	208.0	178.3
Metridia longa	**female**	72.0	86.5	176.0	211.5	56.0	67.3
	male	133.3	69.7	164.0	85.8	48.0	25.1
	C V	202.7	211.7	160.0	167.1	20.0	20.9
	C IV	114.7	34.9	116.0	35.3	16.0	4.9
	C III	66.7	56.0	20.0	16.8	4.0	3.4
	C II	74.7	42.3	8.0	4.5	12.0	6.8
	C I	53.3	57.7	8.0	8.7	8.0	8.7

part of the sediment (Fig. 4.14) but also showed intermediate activity at 1 cm depth. The specific O^2 consumption in the uppermost part of the sediment was only half of that measured in 2005 indicating that the input of organic matter to the sediment during 2006 was significantly lower (Compare with previous ZERO reports). This agrees well with the productive open-water period being shorter during 2006 compared with the previous years.

Sulphate reduction was responsible for 55% of the mineralization of organic

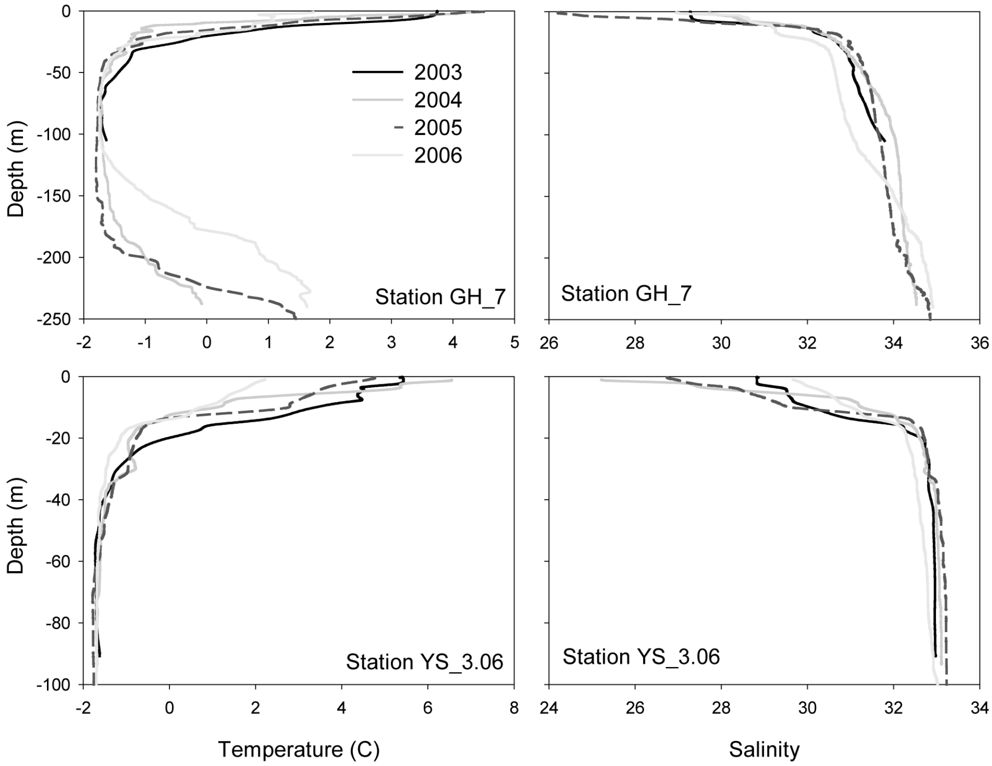


Fig. 4.11. Vertical profiles of temperature (left panels) and salinity (right panels) at two stations from 2003 to 2006.

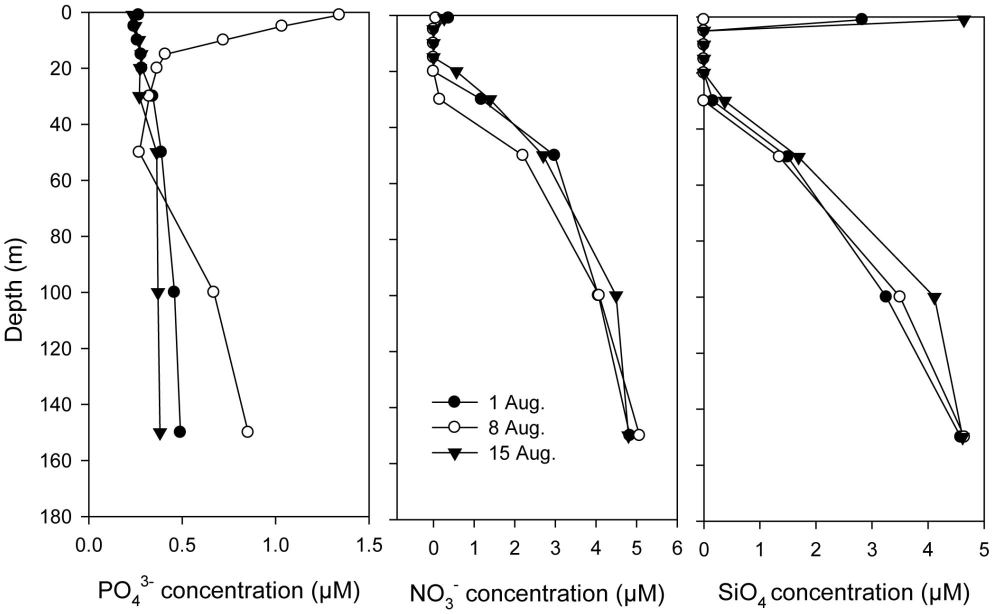


Fig. 4.12. Profiles of the concentrations of nutrients in the water column at the hydrographic station in outer Young Sund in August 2005.

Table 4.6. Sediment-water exchange rates of O_2 (TOU), DIC (dissolved inorganic carbon), NO_3^- + NO_2^-, NH_4^+, SiO_4 and PO_4^{3-} measured in intact sediment cores, sulphate reduction rates (SRR) in the sediment integrated to a depth of 12 cm, diffusive oxygen uptake by the sediment (DOU) and the ratios of DOU to TOU and SRR to DIC flux. SRR/DIC flux is calculated in carbon-equivalents. n denotes the number of sediment cores. Positive values indicate a release from the sediment to the water column. All rates are in mmol m^{-2} d^{-1}. SE denotes the Standard Error of the mean.

Parameter	Average	±SE	n
TOU	-3.203	0.500	10
DIC	3.217	0.451	10
NO_3^- + NO_2^-	0.129	0.017	10
NH_4^+	-0.003	0.022	10
PO_4^{3-}	-0.023	0.018	10
SiO_4	0.601	0.103	10
SRR	0.880	0.309	3
DOU	-3.130		
TOU/DOU	1.02		
SRR/DIC	0.547		

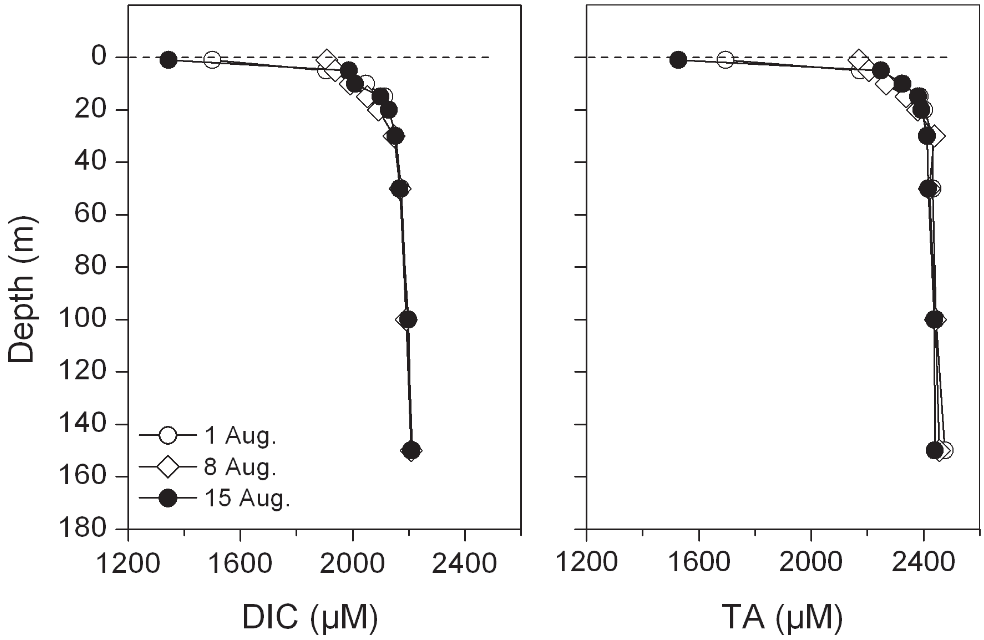


Fig. 4.13. Concentration of dissolved inorganic carbon (DIC) and total alkalinity (TA) in the water column in the outer part of Young Sund, August 2006.

matter in summer 2006 (Table 4.6), which is the highest recorded in the monitoring program. Sulphate reduction was low in the upper layers of the sediment, where other mineralization processes dominated, and increased significantly with depth (Fig. 4.15). Diffusive and whole-core O_2 uptake were identical in 2006, indicating that the role of benthic fauna in mineralization was not significant.

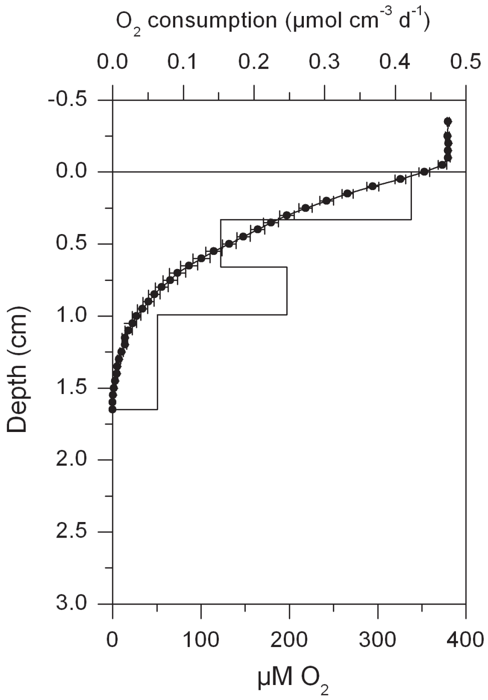


Fig. 4.14. Vertical concentration profiles of oxygen (dots) and modeled consumption rates (bars) in the sediment at 60 m depth in outer Young Sound, August 2006.

Benthic macrofauna

The abundance of dominant epibenthic macrofauna was estimated from 150 photos of the seafloor covering a total of 29.5 m^2. Photos were taken along three transects in outer Young Sund (see Fig. 4.2) covering depths from 20 to 60 m. Brittle stars are the most abundant group, and show increasing abundance with depth (Fig. 4.16), reaching average densities of several hundred individuals per m^2 (Fig. 4.17) Bivalves, primarily belonging to the species *Mya truncata* and *Hiatella arctica*, are especially abundant at depths from 20 to 40 m. Sea urchins belonging to the genera Strongylocentrotus spp. are usually encountered at sites with an abundance of rocks and pebbles, which dominate around 30 m depth.

When average densities at the three transects from 2003 to 2006 are compared, significant variation is observed between years, but with no obvious trend. Data for brittle stars are shown in Fig. 4.18 as an example. It is well known that small-scale variation (meter scale) in sediment structure influences benthic abundance and certainly contributes to sampling variability, but the continued data record

Table 4.7. Annual growth of Laminaria saccharina *in Young Sound.*

	2003 Mean ± SE (N)	2004 Mean ± SE (N)	2005 Mean ± SE (N)	2006 Mean ± SE (N)
Length of new leaf blades (cm yr^{-1})	108.6 ± 7.6 (14)	105.7 ± 6.2 (16)	118 ± 5.5 (20)	77 ± 6.6 (20)
Production of new leaf blades (g C yr^{-1})	15.1 ± 1.3 (14)	5.8 ± 0.8 (16)	11.0 ± 0.9 (20)	2.0 ± 0.5 (17)

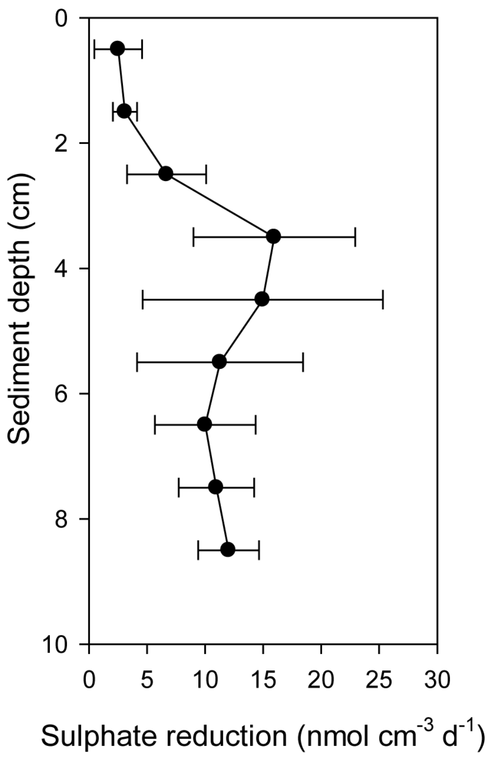


Fig. 4.15. Sulfate reduction rates in the sediment at 60 m depth in Young Sund during August 2006.

will provide important information on year-to-year variability of macrobenthos in the Arctic. In addition to monitoring abundance of dominant groups, a further purpose of seafloor photography is to document changes in species composition. In 2005 and 2006, increasing numbers of the small bivalve Propeamussium groenlandicum (see Fig. 4.17) have been observed on the photos. Very little is known about the ecology of this species, and more data are needed before it can be established whether it is actually increasing in abundance.

Underwater plants

The annual growth of individual specimens of Laminaria saccharina can be estimated by measuring the length of the new leaf produced. In addition to measuring the length of the new leaf, the carbon content of the leaf is also determined. Annual growth in cm and g C yr^{-1} from 2003 to 2006 is given in Table 4.7. Compared with previous year, the annual growth, both in terms of length and carbon content was reduced in the 2005-2006 growth season. In fact, they are back to "normal" open-water conditions as reported by Borum et al. 2002.

4.4 Other activities: Walrus and arctic char

The abundance of walruses at their haul-out location Sandøen was determined on 33 occasions from 4 July to 16 August. On average 17 ± 1.4 (SE) individuals were observed with a range of observation from 1-32. More details on walrus abundance

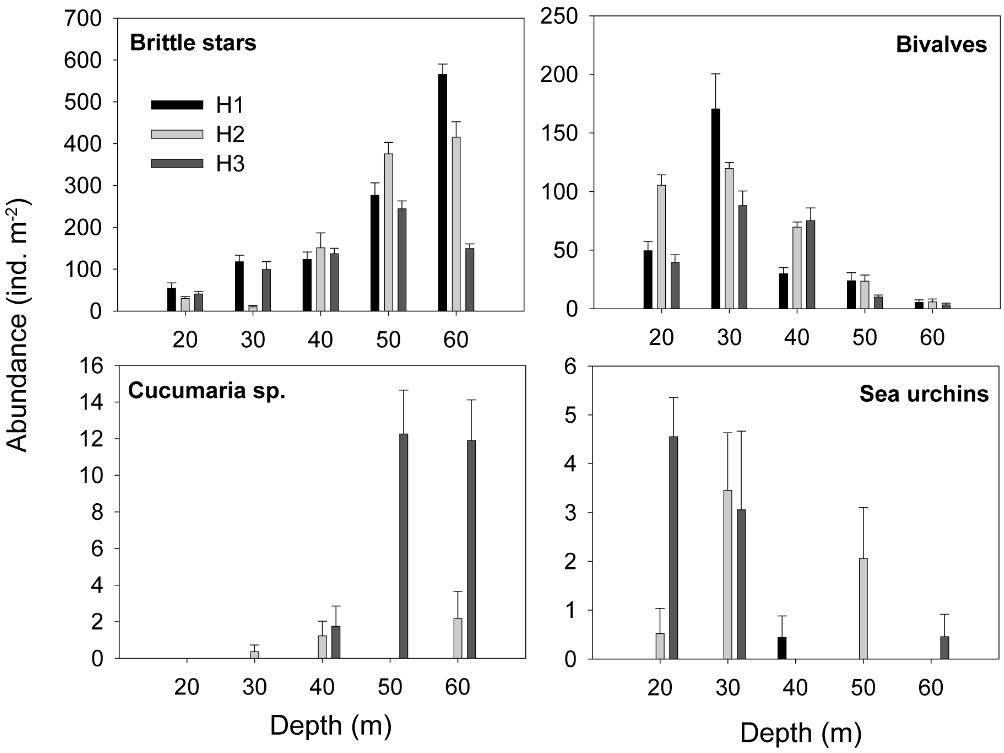


Fig. 4.16. Abundance of dominant benthic fauna in Young Sund estimated from photos of the sea floor taken in August 2006. Mean ± SE, n = 10.

are presented by Levermann *et al*. (section 5.9). MarineBasic also collected material from Arctic char in connection with the catch made by SIRIUS. The material was frozen and may be used in the future as data bank of contaminants etc.

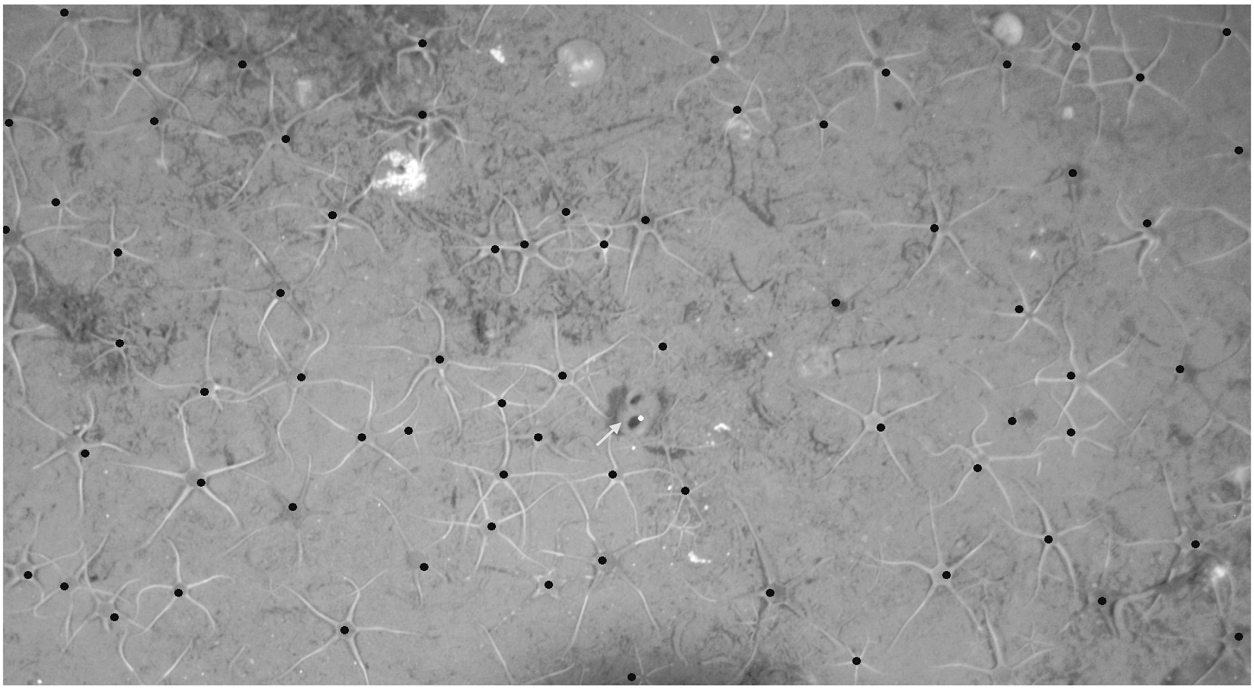


Fig. 4.17. Example of macrofaunal abundance from Young Sound (transect H1, 60 m depth). The dominance of brittle stars at the deeper stations is obvious. A single siphon of a bivalve most likely Hiatella arctica is indicated with green arrow. An individual of the small bivalve Propeamussium groenlandicum *is indicated with a red arrow.*

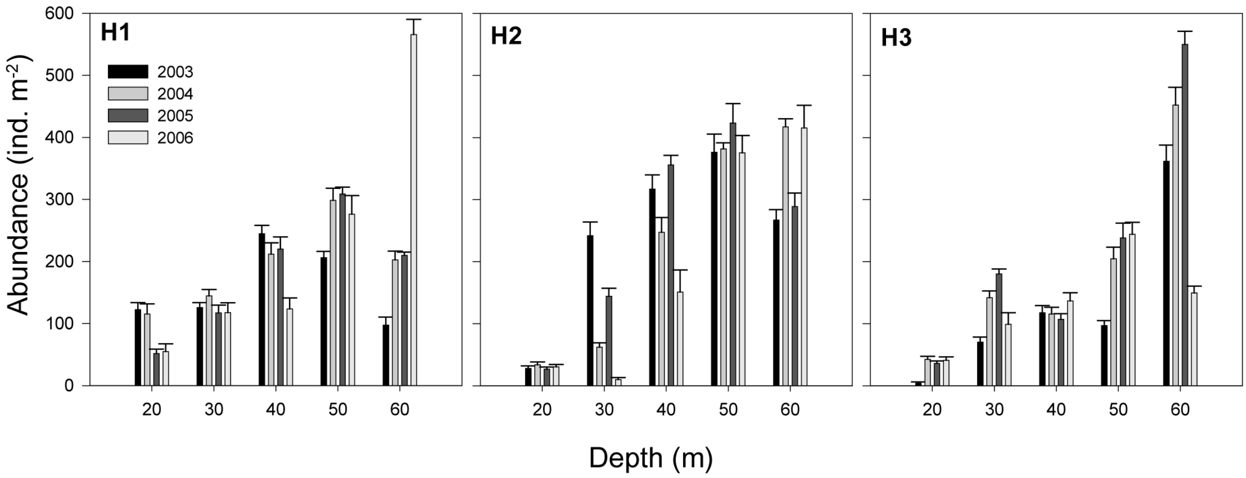


Fig. 4.18. Abundance of brittle stars estimated from seafloor photography in outer Young Sound from 2003 to 2006.

5 Research projects

5.1 Effects of current UV-B fluxes on high arctic vegetation (UV-exclusion experiments)

Kristian R. Albert, Marie Arndal, Helge Ro-Poulsen, Anders Michelsen and Teis N. Mikkelsen

Studies of effects of ambient UV-radiation reduction on plant performance were continued in 2006 as described in previous ZERO reports. Basically the rationale behind the experimentation is that if UV-radiation affects plant photosynthetic performance negatively, then removal of a high proportion of UV-radiation leads to a measurable stress release. The four experimental sites comprises four treatments consisting of an open control (C), filter control (F), UV-B screening filters (UV-B) and UV-AB screening filters (UV-AB) under which the responses of photosynthetic performance parameters on *Betula nana*, *Vaccinium uliginosum* and *Salix arctica* are investigated. Besides the regular monitoring of *Salix* and *Vaccinium* by recordings of chlorophyll fluorescence parameters, vegetation cover by pin-point method and leaf harvest for determination of contents of carbon, nitrogen, chlorophyll and UV-B absorbing compounds, we also focused on two other UV-B issues. First, motivated by earlier year's findings, we investigated whether *Betula nana* is particular UV-sensitive. Second, we investigated the underlying mechanisms responsible for the UV-induced response. We suspected an interaction between plant oxidative metabolism and UV-B stress, which urged us to make a pilot investigation. We applied an artificial plant protective compound EDU (N-[2-(2-oxo-1-imidazolidinyl) ethyl]-N'-phenylurea) to the leaves, which is known for its protective effects against oxidative damage, and reasoned that if oxidative metabolism was involved in UV-effects, the application would reduce the UV-caused plant stress.

Establishment of the experimental plots were planned to be carried out as early as practically possible just after snow melt. This should facilitate an investigation of the impact of spring UV-fluxes, which is important as UV-B radiation levels are highest during spring according to observations on site. Unfortunately the late snowmelt and prolonged permafrost made this difficult, but all sites were established 5-10 days after snow melt, in late June 2006. Measurements were initiated as soon as the leaves had a sufficient size, about 7 days later. At this early point treatment effects were present for all three investigated species: *Salix arctica*, *Vaccinium uliginosum* and *Betula nana*. This pattern was consistent during the field season, where both the maximum quantum yield (F_v/F_m) and the Performance index (PI) were significantly higher in UV-reduced treatments (UV-AB and UV-B) compared to the filter control

Table 5.1. Maximum quantum yield (F_v/F_m) and Performance Index (PI) for Salix arctica, Vaccinium uliginosum *and* Betula nana *2006. Seasonal mean and standard error are for all treatments - open control (C), filtered control (F), UV-B reduction (UV-B) and UV-AB reduction (UV-AB). Results from variance statistical analysis (PROC GLM in SAS) are shown; treatments which share letters on top of bars are not significantly different in Tukey's test.*

Maximum photochemical effectivity (F_v/F_m) 2006 (Mean and std.error based on all redcorded values during season)

Species	Site	UV-AB	UV-B	C	F	Fvalue	ProbF
Salix arctica	1	0.7746± 0.0049 A	0.7699± 0.0047 AB	0.7293± 0.0055 C	0.7510± 0.0072 B	12.93	<0.0001
	2	0.7419± 0.0065 AB	0.7461± 0.0049 A	0.6953± 0.0096 C	0.7217± 0.0054 B	13.71	<0.0001
Vaccinium uliginosum	1	0.7323± 0.0103 A	0.7258± 0.0093 AB	0.6840± 0.0120 C	0.7045± 0.0096 CB	11.94	<0.0001
	2	0.7174± 0.0108 A	0.7246± 0.0076 A	0.6695± 0.0132 C	0.6996± 0.095 B	5.45	0.0011
Betula nana	3	0.7261± 0.0077 A	0.7203± 0.0070 A	0.6588± 0.0116 B	0.6669± 0.0092 B	17.79	<0.0001

Performance Index (PI) 2006 (Mean and std.error based on all redcorded values during season)

Species	Site	UV-AB	UV-B	C	F	Fvalue	ProbF
Salix arctica	1	5.011 ± 0.2828 A	4.366 ± 0.2869 AB	2.879 ± 0.1989 C	3.7319 ± 0.2349 CB	13.14	<0.0001
	2	3.419 ± 0.4188 A	3.204 ± 0.2551 A	2.346 ± 0.2829 B	2.1986 ± 0.1814 B	10.39	<0.0001
Vaccinium uliginosum	1	3.542 ± 0.2649 A	3.059 ± 0.2388 AB	2.111 ± 0.1717 C	2.4690 ± 0.1653 CB	13.68	<0.0001
	2	3.131 ± 0.3277 A	2.805± 0.2847 A	2.147 ± 0.2534 AB	2.089 ± 0.2206 B	3.24	0.0221
Betula nana	3	2.773 ± 0.1988 A	2.658 ± 0.1857 A	1.839 ± 0.2012 B	2.033 ± 0.1399 B	8.799	<0.0001

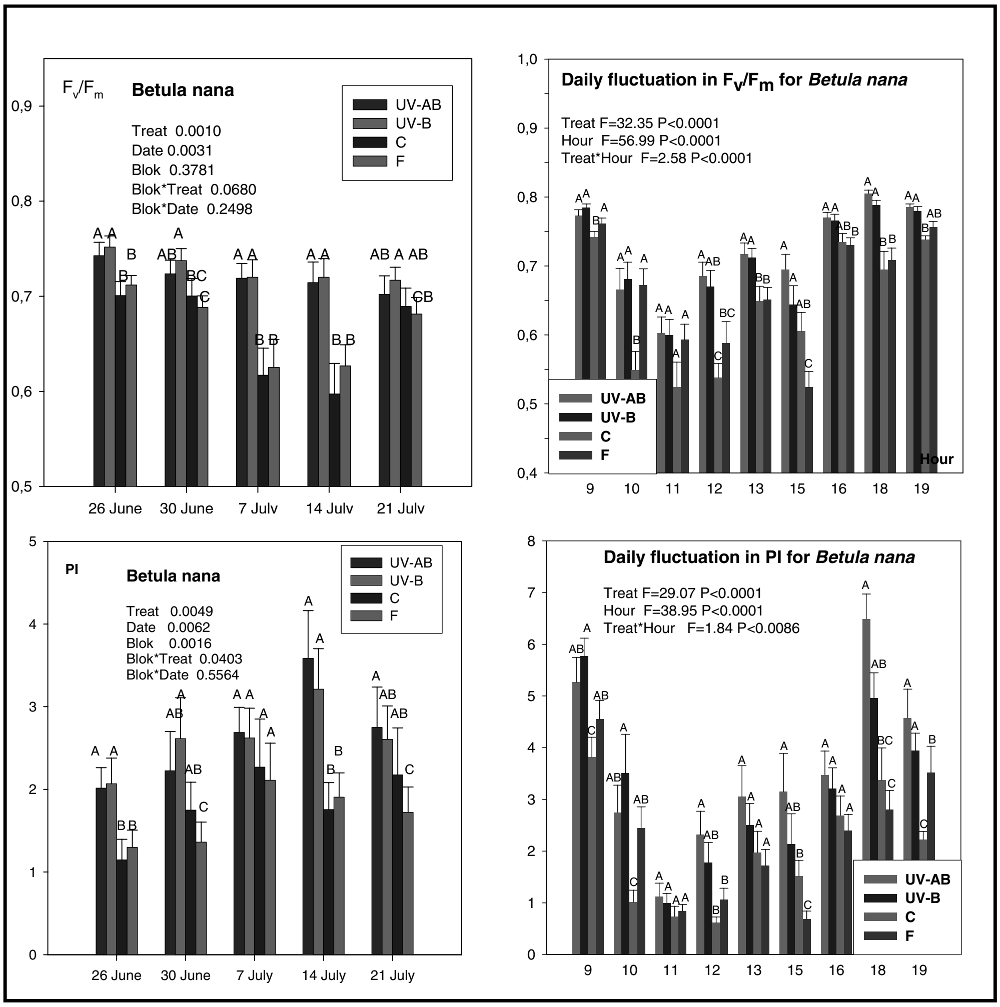


Fig. 5.1. Maximum quantum yield (Fv/Fm) and Performance Index (PI) for Betula nana *2006. Seasonal (left) and daily (right) mean and standard error are depicted for all treatments - open control (C), filtered control (F), UV-B reduction (UV-B) and UV-AB reduction (UV-AB). Results from variance statistical analysis (PROC GLM in SAS) are shown; treatments which share letters on top of bars are not significantly different in Tukey's test.*

(F) (Table 5.1). Moreover values of F_v/F_m and PI for *Vaccinium uliginosum* and *Salix arctica* were lower on site 2 versus site 1. This clearly indicates stronger UV-B effects on the sloping site 2 versus the level site 1, in parallel with higher received UV-B dose due to higher exposure to incoming irradiance. The magnitudes of PI reflected the seasonality of photosynthetic performance, with initially low values increasing to a peak in mid July, whereafter senescence probably was responsible for the later lower values (Fig. 5.1). This clearly indicates that current UV-radiation acts as a stressor on the investigated plants and that fluorescence parameters are good measures of plant seasonality.

Betula nana is a common dwarf shrub in the sub-arctic southern Greenland, and while it is currently rare in the Zackenberg area, it seems to become more frequent (Albert, K.R. pers. obs.). This may be due to the more favorable growth conditions mediated by the warmer climate in the Zackenberg area the last decade (11th ZERO report). Inter-species differences in plant photosynthetic performance characteristics are important since the traits very likely influence competition and the resulting plant cover. Therefore a comparison to the abundant occurring *Salix* and *Vaccinium* is interesting. Our emphasis on the response in *Betuala nana* led to following initial conclusions. The level of F_v/F_m and PI values in *Betula nana* is lowest in all treatments (including controls) in both 2005 and 2006 compared to *Salix* and *Vaccinium*, which clearly indicates a higher stress level in *Betula*. Therefore UV-effects are expected to be more pronounced in this species. Indeed, we observed significant negative UV-effects both across the season and on a daily basis (Fig. 5.1), in parallel with observations from the 2005 season (see 11th ZERO report). During the period of measurements, *Betula* seemed permanently stressed by the current level of UV-B radiation, as neither F_v/F_m nor PI in the filtered control (F) catch up the level in the UV-B or UV-AB at any time of the day (Fig. 5.1). Addition of EDU (applied the evening prior to measurements) signifi-

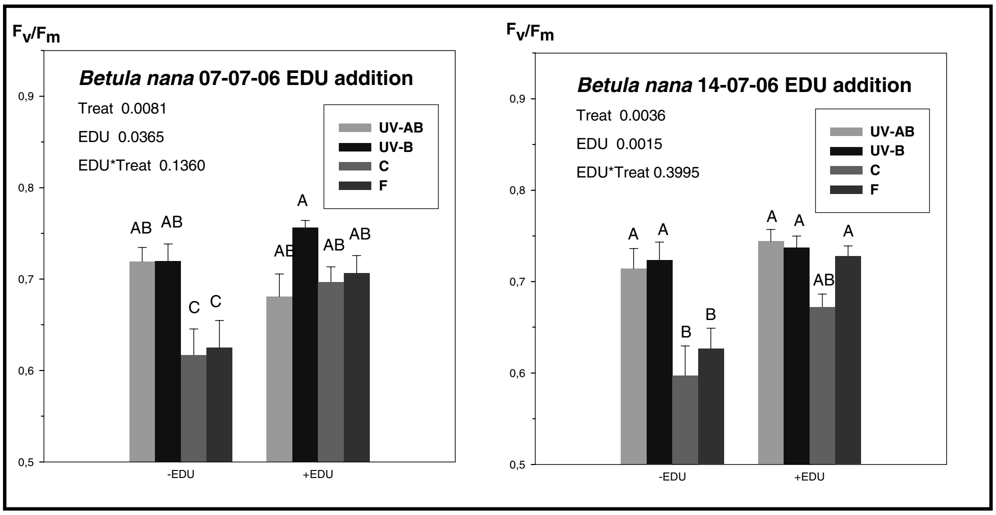


Fig. 5.2. Maximum quantum yield (Fv/Fm) before and after EDU addition for Betula nana *2006. Mean and standard error are depicted for all treatments - open control (C), filtered control (F), UV-B reduction (UV-B) and UV-AB reduction (UV-AB). Results from variance statistical analysis (PROC GLM in SAS) are shown; treatments which share letters on top of bars are not significantly different in Tukey's test.*

cantly increased F_v/F_m in all treatments in *Betula*, but the increase were clearly highest in the controls (F, C) (Fig. 5.2). The increase in the control treatments (F and C) resulted in disappearance of significant UV-effects (Fig. 5.2). This indicates that the molecular function of EDU interacts with the mechanisms causing UV-effects. The stress release in ambient UV-B induced by EDU is surprising and the application of EDU under field conditions in relation to UV-B is the first of its kind. Additional investigations of whether EDU are acting systemically or if the compound itself absorbs UV-B are to be tested. However, as the stress release was most pronounced when EDU was provided in ambient UV-B and an already high level of UV-B absorbing compounds in ambient UV-B was expected, the impact is most likely systemic.

5.2 Effects of manipulations of local climate on processes and organisms in high arctic terrestrial ecosystems

Anders Michelsen, Susanne Ellebjerg, Marie Arndal, Mikkel Tamstorf, Niels M. Schmidt, Lotte Illeris, Kristian R. Albert, Helge Ro-Poulsen

With experimental manipulations the effects of components of local climate on processes and organisms in ecosystems can be explored. In order to elucidate effects of climate on carbon balance and plant performance, experiments have been maintained from 2004 to 2006 in two heath types at Zackenberg, a *Salix arctica* and a *Cassiope tetragona* dominated heath.

In each of the two heath types, the gas exchange and plant performance has been followed closely through the growing season in 25 plots of 1 m^2. The treatments consist of plastic tents which increase the soil temperature by 1.0 °C in order to simulate slightly increased summer temperature, snow removal and addition treatments which prolong and reduce the growing season length by 3-8 days and 1-4 days, respectively, a 50 % shading treatment which simulates denser cloud cover and reduces soil temperature by 2.0 °C, and non-manipulated control plots. As data from gas exchange measurements have been presented in the annual report of 2005, we here focus on some of the plant responses.

Nitrogen is a key nutrient for plants, and is often the most limiting factor for plant growth in northern ecosystems with slow turnover of organic matter. In *Salix* exposed to 50 % shading the growth was reduced due to lower photosynthesis, while the leaf nitrogen concentration increased, in 2006 from 2.6% to 2.9%. This plant response, which is due to increased formation of chlorophyll and serves to capture and fully use the weaker sunlight, suggests that nitrogen may not be a prime growth limiting factor in this ecosystem. Shaded plants hence have increased nutritional value for grazing animals, which may affect plant cover if the cloud cover is increased considerably or taller canopy-forming and shading plant species expand their distribution.

While there was too few individuals of *Salix arctica* to evaluate effects of flowering, there was up to 600 flowers per m^2 of *Cassiope tetragona*, with a general decrease in flower density in all plots from 2004 through 2006 (Fig. 5.3). The shading treatment decreased mean flower density in 2005 and 2006 by 77% and 84%, respectively, compared to the control plots (Fig. 5.3). Shaded *Cassiope tetragona* does not have enough resources to form flowers, since it is likely to often suffer from reduced light limiting photosynthesis and affecting plant carbon balance. Hence, our experiments clearly suggest that *Cassiope tetragona* will not be able to produce many flowers if cloud-cover increases strongly and/or these dwarf shrubs are overgrown by a canopy of potentially taller shrubs such as the dwarf birch, *Betula nana*.

Manipulations of growing season length had only limited effect on flower density. Plots in which snow was removed manually early in the season had a significantly longer growing season of 3–8 days in all three years and there was a tendency towards higher plant cover in *Salix arctica* plots in 2006, but this difference was not reflected in a difference in *Cassiope tetragona* flower density, neither in 2005 nor in 2006. This may be because the longer growing season was not sufficient to provide the plants with additional resources to the extent that more flower buds could be formed for the following growing season, as has been shown for this species from the monitoring plots. However, there was a tendency for short growing season plots to have lower flower density than controls in 2006 (Fig. 5.3). Hence, increasing growing season length without a corresponding increase in temperature does not seem to increase flower density in *C. tetragona*, whereas only a small decrease of season length may limit flower development.

The effects of warming were less pronounced than those of shading, but in 2006 there was a tendency for temperature increased plots to show lower flower density than the controls. This result is somewhat surprising, since a higher total heat sum during the previous growing season has been shown to increase the total number of flowers m^{-2} in current year in *C. tetragona* during ten years of monitoring at Zackenberg. One explanation for the tendency towards reduced flowering in warmed plots could be that the 1ºC increase was too small to have a direct positive effect on the flowering frequency, but that warming led to drying of the soil surface by increased evaporation combined with screening of precipitation.

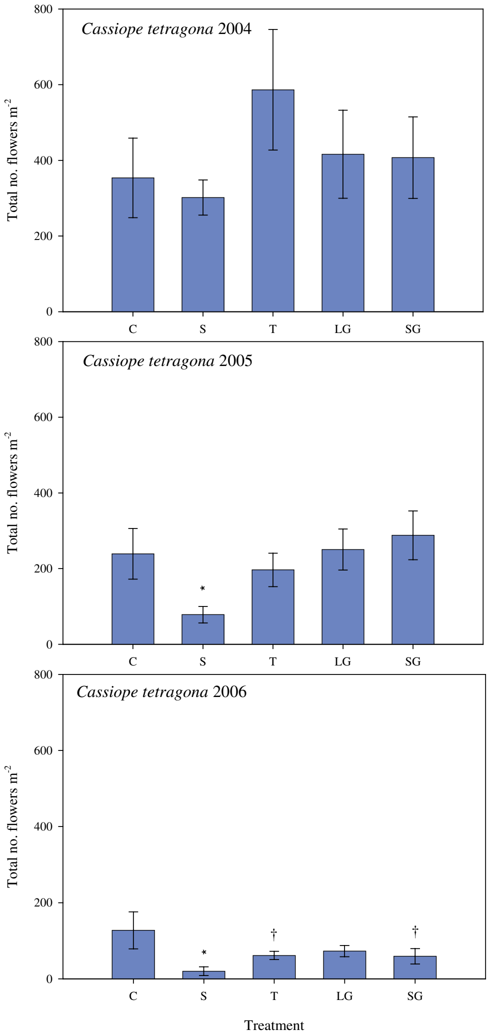


Fig. 5.3. Total number of flowers m^{-2} in Cassiope tetragona *subjected to five experimental treatments simulating climate change in the summers of 2004, 2005 and 2006. Treatments were C: Control, S: Shading, T: Increased temperature, LG: Prolonged growing season and SG: Shortened growing season. Means ± standard error. † denotes a tendency for a treatment effect (Dunnett's test, $p < 0.12$); * denotes a significant treatment effect (Dunnett's test, $p < 0.05$).*

5.3 Spatial variation in growth and phenology of arctic willow

Ditte K. Hendrichsen, Gösta Nachman and Mads C. Forchhammer

Snow cover is known to influence the growth and timing of arctic plants (Galen and Stanton 1995) and probably pivotal for the spatio-temporal functioning of arctic ecosystems (Meltofte 2002). For example, extensive snow cover with a late snow melt in summer may decrease the growth season of plants significantly (Mølgaard and Christensen 1997, Grøndahl 2006), whereas snow cover during winter can protect plants from damage due to frost and wind. Loss of potential days of growth following delayed snow melt may affect the trade off between growth and reproduction for individual plants. In the Zackenberg valley, there is considerable spatial variation in the snow cover within a given year, as well as significant between-year differences (Hinkler 2005).

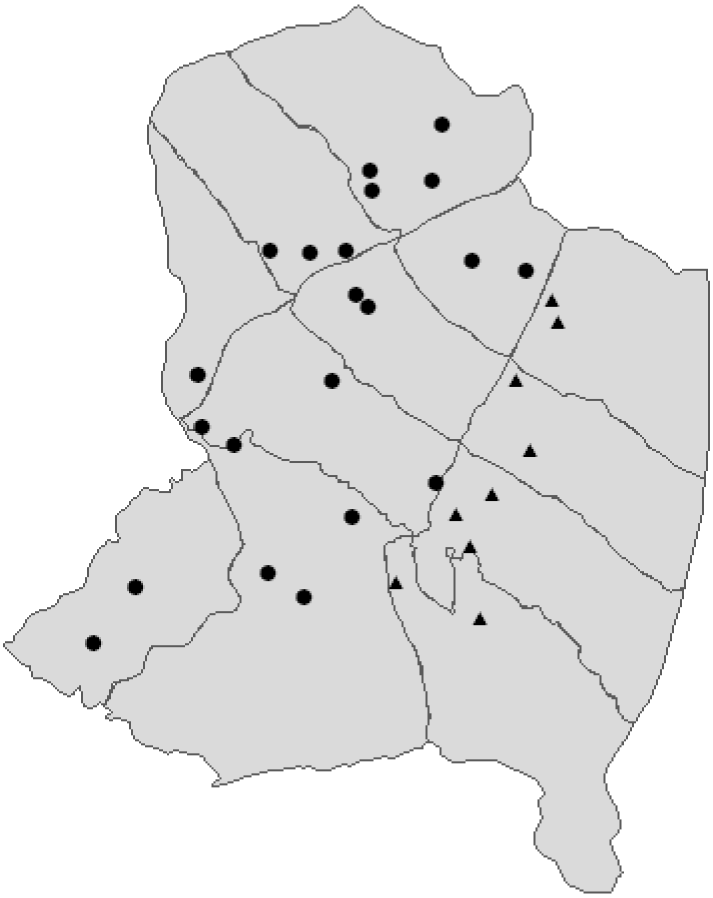


Fig. 5.4. Map of the 12 snow monitoring zones in Zackenberg with position of the 30 Salix *plots. Phenology was registered in all 30 plots in July and August. Subsequently, samples for dendrochronogical analyses were collected in 21 of the plots, ● The remaining nine plots, ▲, were positioned in the protected zones 9-12, and no samples for dendrochronological analyses were collected at these plots.*

Hence, we would expect that the growth and flowering phenology of individual plants of arctic willow *Salix arctica* vary accordingly, resulting in spatial variation between plants experiencing different conditions within the valley.

To investigate the interaction between snow, growth and reproductive phenology in *Salix arctica*, a series of 30 plots were established covering the 12 zones, which are continuously monitored for snow cover (Fig. 5.4) (Canning and Rasch 2003). The position of plots covered a range of localities with respect to biotic and abiotic parameters, such as altitude, exposure, snow conditions and vegetation. Plots were established primo July 2006, and revisited approximately weekly until medio August. The development of *Salix* within each plot was examined following the procedures of Meltofte and Berg (2004) with respect to flowering phenology and RVI. At the end of the season, six plants, three males and three females, were collected for later dendrochronological analyses at 21 of the 30 plots. Dendrochronological analyses allow the investigation of the year-to-year growth of individual plants, based on the radial growth patterns of the plant (Schmidt *et al*. 2006). Nine of the plots, however were located within the protected snow zones 9-12, thus in these plots the phenology was registered as stated above, but no plants were harvested (Fig. 5.4). Previous studies have shown that the growth of *Salix* at Zackenberg may be traced back 90-100 years using dendrochronological analyses (Schmidt *et al*. 2006), and the relationship between snow, phenology and growth is currently being investigated based on data from the BioBasis monitoring (Canning and Rasch 2004).

With this study we aim at expanding the analysis, embracing the entire monitoring zone, to investigate the growth patterns of *Salix arctica* at a broader spatial scale. The preliminary analyses point towards marked differences in the timing of flowering between plots, influenced by factors such as altitude, snow cover and vegetation type. Finally, since *Salix arctica* constitutes one of the main forage plants of the muskoxen *Ovibos moschatus* in the area, we also investigate the interactions between the growth of *Salix* and the spatial habitat use of the muskoxen.

5.4 Ressource allocation and allometry of plant growth in the Arctic: key constraints on change and predictability of the arctic system

Gaius R. Shaver, Lorna Street, Mark van Wijk, Peter van Buuren, and Craig Menzies

Arctic landscapes are characterized by extreme vegetation patchiness, often with sharply-defined borders between very different vegetation types. The different patches of arctic vegetation can differ sharply in their productivity, carbon balance, and other measures of element cycling over short distances as well as over long climate gradients. This patchiness makes it difficult to predict regional- or landscape-level C balance and its change in response to environmental change. Most models of regional arctic C cycling use patch-based approaches, however, because the available data are typically collected on a patch-by-patch basis, with patches classified by dominant species or functional type in the vegetation. In this study the aim is to develop new models of

CO_2 balance that are independent of the species composition of vegetation and that rely on variables that change continuously across the Arctic region.

In previous research at Low Arctic sites at Toolik Lake, Alaska and Abisko, Sweden, a model was developed that predicts Net Ecosystem Exchange (NEE) of CO_2 in arctic ecosystems using a single parameterization applied to a wide range of Low Arctic vegetation types; the only input variables are air temperature, photosynthetic photon flux density (PPFD), and a measure of leaf area derived from NDVI, the Normalized Difference Vegetation Index. The model explains ~80% of the variation in NEE among a wide range of Low Arctic sites, and parameterizations developed from a single Low Arctic site can be used to predict NEE at other sites with the same accuracy as parameterizations developed at the sites where NEE is predicted.

In summer 2006, the light response of NEE was measured in diverse sites at Zackenberg, along with associated measurements of air temperature, PPFD, NDVI, leaf area, and vegetation cover and composition. The aim of this work was to develop a data set that encompassed the variation in NEE and its major controls in the ecosystems available for sampling at Zackenberg. The Zackenberg data could then be compared with the two similar Low Arctic data sets available from Toolik Lake and Abisko, and with a second High Arctic data set collected from Svalbard, Norway, in 2005.

The NEE measurements were made by sequential shading of a clear plastic cuvette attached to a LiCor 6400 photosynthesis system. The cuvette was placed over a removable base, with a seal achieved between base and ground surface by weighting a plastic skirt with a heavy chain. NDVI was measured with a portable spectroradiometer, and the NDVI-leaf area relationship was described by measuring NDVI in small plots, sampling all the leaves, and determining leaf area using a portable scanner.

Preliminary results indicate that a high-quality, usable data set was collected including 59 NEE light response curves. The NEE results from Zackenberg are similar to and within the same range as those from Alaska, Sweden, and Svalbard (Fig. 5.5). NEE at a constant PPFD of 600 µmol photons/m^2/s is clearly correlated with NDVI and leaf area. One tentative conclusion is that NEE and Gross Primary Production (GPP) per unit leaf area are usually higher in High Arctic sites (Zackenberg and Svalbard) than in Low Arctic Sites (Toolik and Abisko). This may be related to a tendency toward higher N concentrations in leaves in High Arctic sites. If so, the original model may have to be modified to account for variation in N concentration if we are to use a single parameterization to predict NEE throughout the Arctic.

5.5 Studies in basidiomycetes (fungi) in the Zackenberg-area in 2006.

Torbjørn Borgen Lindhardt

In the field season of 2006 I spent 4 weeks in the Zackenberg area (incl. Daneborg) on studying (collecting, describing, photographing and drying) terrestrial fungi (mainly basidiomycetes) in as many habitats as possible.

In the first week (July, 26th to August, 1st) I made 62 collections, representing over 30 species at Daneborg. Between August 2nd and August 23th I made 203 collections, representing about 140 species at Zackenberg. In total about 145 species were recorded from the area, of which at least 40 are new to the area.

The collections from the very Zackenberg area were largely made within zone 1A. Only a couple of collections were made from zone 1C (at Lomsø), while about 25 collections were made on and around Ulvehøj (zone 1B).

Far most of the field trips were made E of Zackenberg river; this means that the basaltic/sedimental bedrocks are overrepresented compared to the gneissic region W of the river.

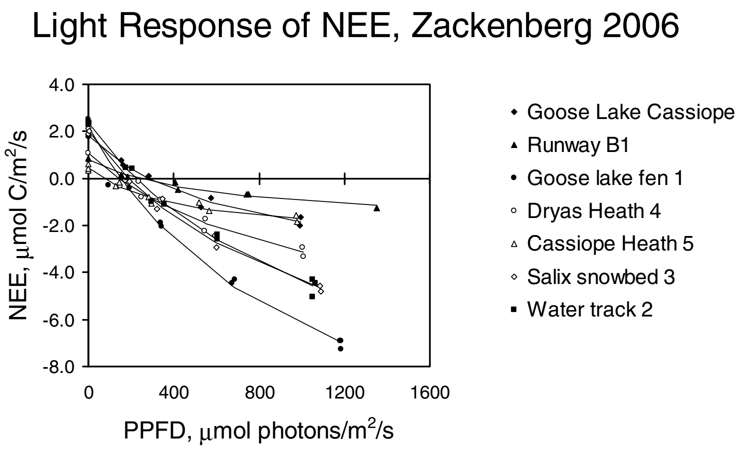


Fig. 5.5. Light response of Net Ecosystem Exchange (NEE) of CO_2 in selected plots at Zackenberg, July 2006. These curves were selected as illustrative of the range of data collected. At low Photosynthetic Photon Flux Density (PPFD), respiration predominates and CO_2-C is added to the atmosphere (NEE is a positive value); at high PPFD photosynthesis predominates and CO_2-C is removed from the atmosphere (NEE is negative).

In the very dry, hot summer of 2006 the dry habitats were unfavourable, while the moist habitats, like fens and moist grasslands, were quite good.

Most of the material is now identified, but it is anticipated that many of the unidentified species are new to science. During this year the remaining collections will be worked up for a comprehensive report on the results from 2006 and 1999, comprising i.e. a commented check list.

The taxonomic results will mainly be included in a book on the Basidiomycetes in Greenland, by Henning Knudsen (Botanical Museum, University of Copenhagen), Steen A. Elborne and myself.

5.6 A soil map for the Zackenberg Valley

Maria Rask Pedersen, Bo Elberling, Charlotte Sigsgaard, Stina Nordmand Rasmussen and Birger Ulf Hansen

Soil types in relation to specific vegetation types in the Zackenberg Valley have previously been described. But major questions remain unanswered in relation to scaling up variations in soil types and characteristics across landscape elements and the entire valley. There is also a lack of functional descriptions of the relationship between 1) soil characteristics, partly controlled by the initial sediment deposition and thus the parent material, as grain size distribution and degree of sorting, 2) degree of water saturation, temperature regime, soil acidification, nutrient availability, and soil element accumulation and 3) ecological characteristics as vegetation type and NDVI (normalized difference vegetation index). The latter characteristics are easier identified based on satellite images and may therefore represent a usefull proxy for mapping subsurface soil characteristics and an important input for evaluating the spatial distribution of soil formation, weathering and active layer development. In order to provide answers of these questions, the project *Soil mapping of the Zackenberg valley, NE Greenland* was initiated the summer 2006.

A soil sampling survey was carried out in July and August and included four dominating vegetation types *Cassiope tetragonal* heath, *Dryas sp*. heath, *Salix arctica* snow bed and grassland in the valley (former SCHAPPE plots) as well as sites along the ZERO-line transect (in total 77 pits, Fig. 5.6). Depth-specific and density-specific soil samples (350) were taken from soil pits to the depth of permafrost. At each location additional measurements included soil temperature, soil moisture, active layer depth and RVI (ratio vegeta-

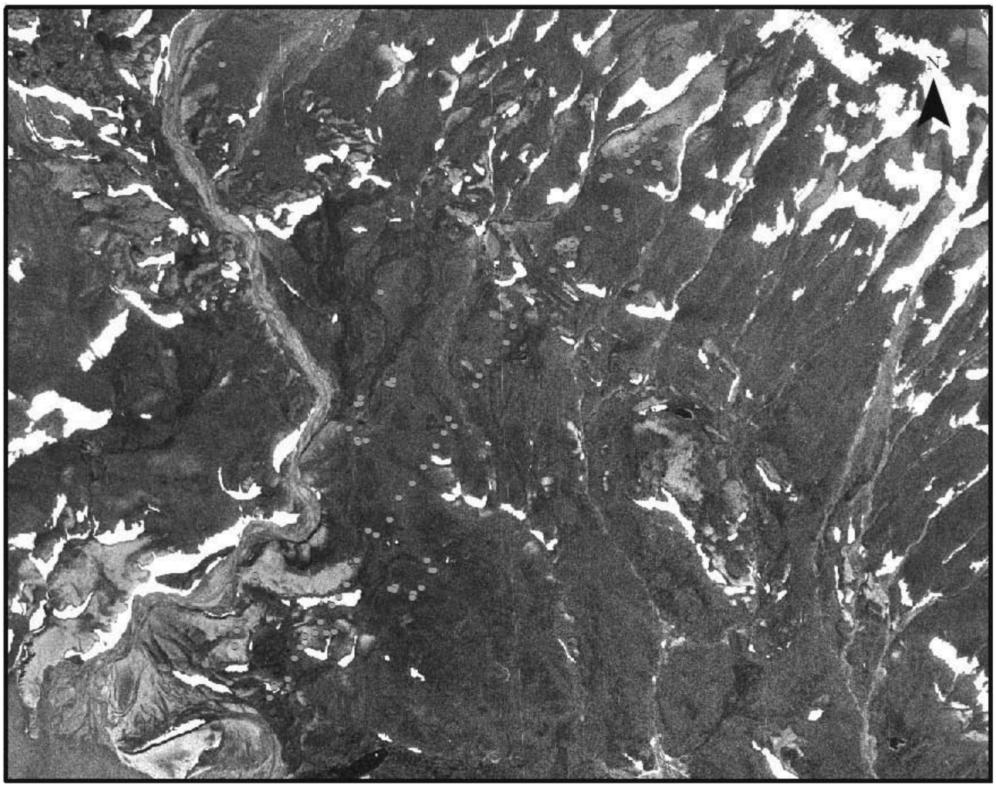


Fig. 5.6. Location of sites sampled as part of soil survey the summer 2006

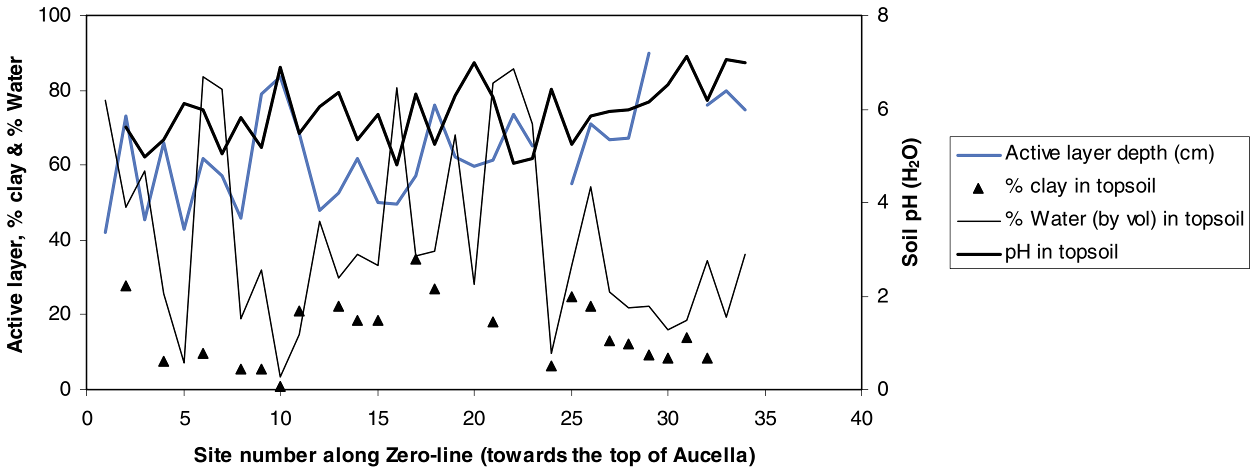


Fig. 5.7. Average topsoil pH, % clay, water content and active layer thickness along the Zero-line.

tion index). Subsequently, soil samples were weighed before and after drying and afterwards 2mm-sieved and analyzed for pH, total organic carbon, texture and total and organic phosphorus at The Department of Geography and Geology (University of Copenhagen).

Preliminary results from sites along the ZERO-line reveal as expected great spatial variation in soil characteristics (Fig. 5.7) but also variations that to some degree can be explained by a set of environmental factors. As a proxy for soil development, pH-values are shown and reveal to be lowest at sites with a high water content. This is in line with variations in the total organic carbon, which is highest in the wettest and most acidic soils (Fig. 5.8). This is consistent with the oxygen-limited decomposition of organic matter at wetter sites and the consequently incomplete decomposition of organic matter (at least part of the summer period) resulting in a net accumulation of humus and production of organic acids lowering the soil pH. At drier sites, a more complete mineralization of organic matter occurs, producing only carbonic acid to drive soil weathering and almost no carbon to accumulate within the soil profile.

These variations are further linked to the parent material as a high clay content tends to allow the soil to retain more water than more sandy sites (Fig. 5.8). However, the location of melting snow beds (Fig. 5.6) deliver water throughout the summer and may therefore keep the water content high at downstream sites despite of well-drained conditions. These complex interactions are needed to be quantified before a more detailed soil map for the Zackenberg Valley can be produced and used for other applications.

A soil map of the Zackenberg Valley is expected to be available as part of a master thesis (by Maria Rask Pedersen) by the end of 2007. This master thesis will further, as a first application of the soil map, use the spatial distribution of soil characteristics to model active layer changes the last 10 years and predict future changes due to global climate changes.

5.7 Air-Sea CO_2 flux in Young Sund and the Greenland Sea

Mikael K. Sejr, Dorte Krause-Jensen, Morten Frederiksen and Søren Rysgaard

Introduction

Atmospheric CO_2 concentrations are increasing by ~1.5 ppm per year (IPPC 1995), partly due to combustion of fossil fuels and deforestation. The ocean can to some extent absorb atmospheric CO_2 and thereby act as a buffer towards these increases, but it is still a question whether coastal waters act as a sink for atmospheric CO_2, and the mechanisms determining the air-sea CO_2 flux are not fully understood. This project aims to assess air-sea CO_2 flux during the summer period in Young Sund, Northeast Greenland and estimate the effect of biological and physical processes on the flux.

A field campaign was conducted in August 2006 that included measurements of CO_2 concentrations in the surface water and in the atmosphere (using a transportable gas analyzer, EMG-4 IRGA) and measurements of total dissolved inorganic carbon (DIC), total alkalinity (TA), temperature, salinity and chlorophyll in the surface water. Measurements were conducted in three dimensions along gradients from the inner fjord to the

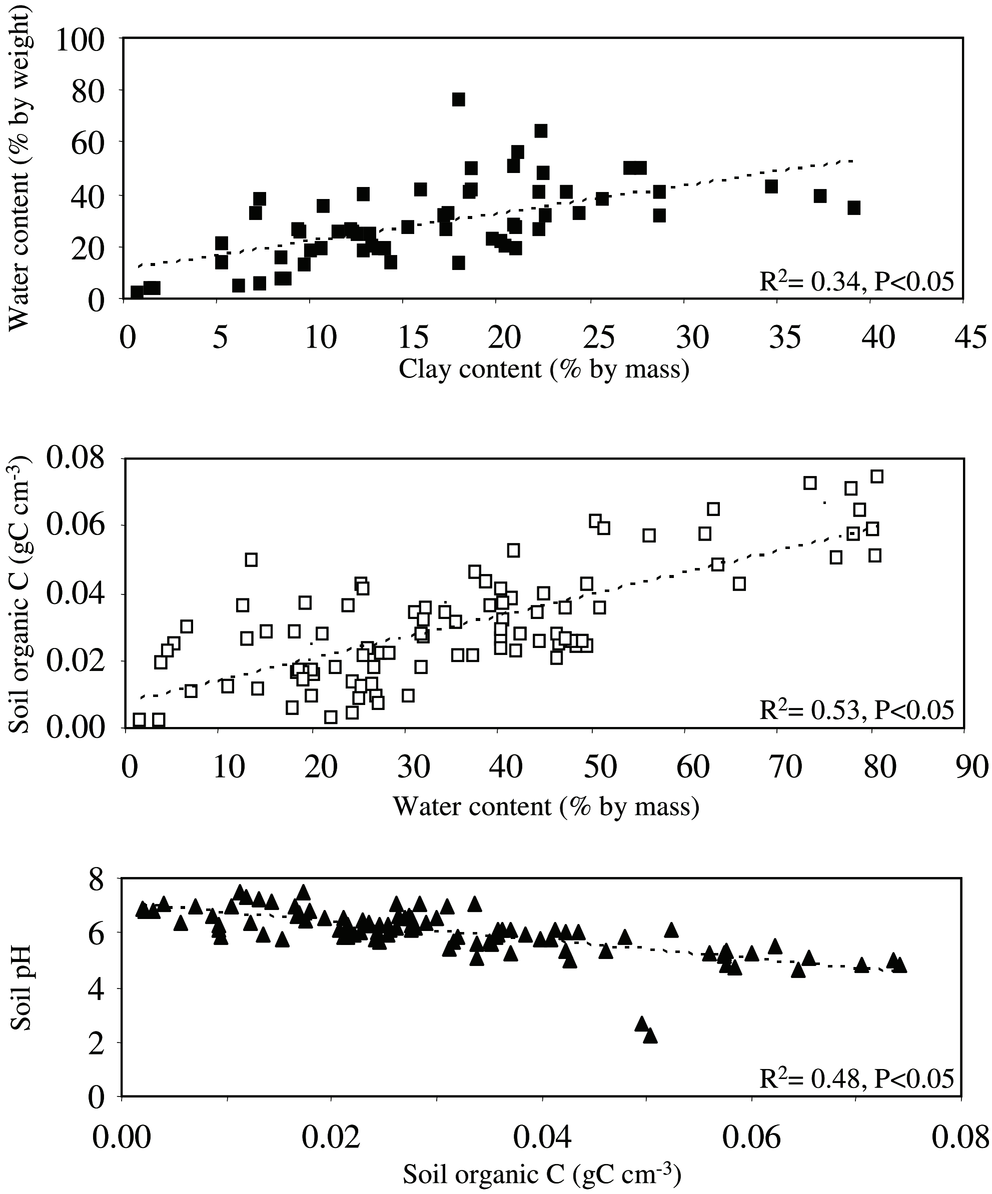


Fig. 5.8. The relationship between soil organic carbon, soil pH, water content and clay content within the upper 30 cm of soil profiles along the Zero-line. Regression lines are shown as dashed lines.

Greenland Sea. Furthermore, the temporal variation was assessed over a diurnal cycle and from week to week.

Spatial variation in ΔCO_2 and related variables in Young Sund

Along the entire fjord system (Fig. 5.9a), partial pressure of CO_2 was lower in surface waters (1 m depth) than in the atmosphere, i.e. ΔpCO_2 was negative and the fjord absorbed CO_2 from the air (Fig. 5.9d). The CO_2 uptake was largest in the inner parts of the fjord system at 'Tyrolerfjord' and in the outer parts towards the Greenland Sea, while the central fjord exhibited a smaller uptake (Fig. 5.9d).

Meltwater from glacial ice renders the surface water of the inner parts of the fjord system brackish (salinity of ca. 6) and cold (6°C). The surface-water salinity increases gradually towards the outer fjord and attains a maximum of 30 in the Greenland Sea. The temperature increases to about 10 °C along the Tyrolerfjord, but then decreases gradually to 1-2 °C in the Greenland Sea (Fig. 5.9b and c).

A multiple linear regression shows that ΔpCO_2 and thus absorption of CO_2 from the air increases as temperature and salinity decline. The relationship is significant and can be expressed as:

ΔpCO_2 =-400.3104 + 4.3447x Temperature + 6.4190 x salinity ($p<0.0001$, $R^2=0.95$)

Variations in temperature and salinity can explain 95% of the spatial variations in ΔpCO_2. Variations in ΔpCO_2 were not related to biological factors such as surface-water concentration of chlorophyll *a* or O_2 saturation, both of which are proxies for primary production. Although primary production directly influences pCO_2 values of seawater, nutrient limitation in the upper 25 m of the water column forces the phytoplankton to descend to depths of 25 to 40 m where peak chlorophyll *a* values (see section on the Marine Basic programme by Rysgaard et al.) and peak oxygen concentrations are found in August. During August, phytoplankton is thus located too deep in the water column to directly influence pCO_2 of the surface water and, hence, the air-sea exchange of CO_2 (Fig. 5.10).

Although primary production was not important for the spatial variation in ΔpCO_2 during August, it most likely played a key role for the generally low pCO_2 values of the surface water. In Young Sund, high primary production takes place in the upper 25 m of the water column following the break-up of sea ice, and a large part of the bloom subsequently sinks out of the water column (Rysgaaard and Sejr 2007). Due to strong stratification in summer, the surface layer remains undersaturated with respect to CO_2, and thus drives the uptake from the atmosphere. In addition to the biological CO_2 uptake from the surface water, the process of formation and melting of sea ice has recently been reported to play an important role as a carbon sink in Polar Seas. The formation of sea ice causes rejection of not only salts but also of inorganic carbon from the ice to the underlying water, which sinks to greater water depths due to its high density. The melting of CO_2-undersaturated sea ice the following spring, leads to low surface-water CO_2 levels, thereby increasing the uptake of atmospheric CO_2 (Rysgaard *et al.* 2007).

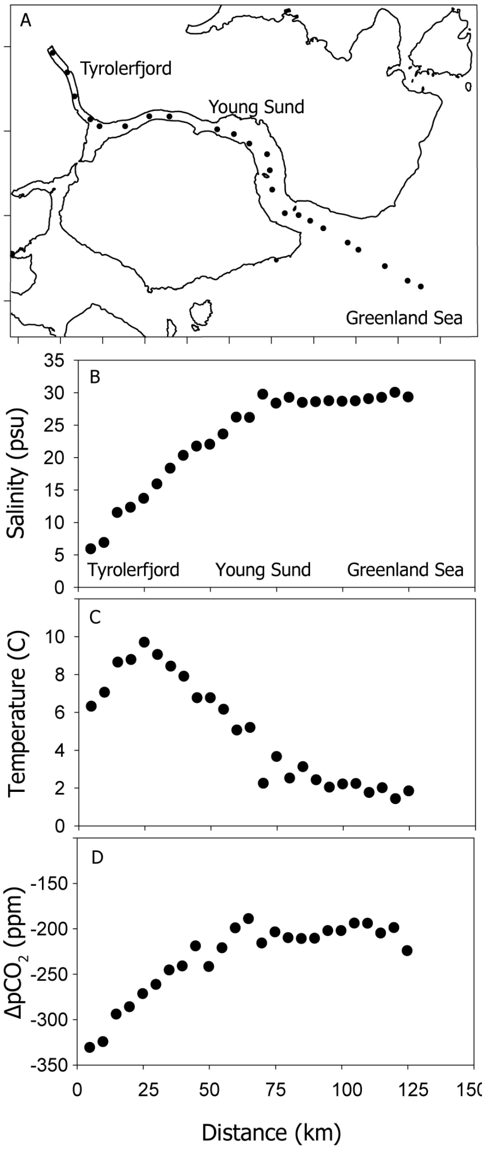


Fig. 5.9. Map showing sampling stations (A), salinity (B), surface temperature (C) and difference in partial pressure of CO_2 of air and sea (ΔpCO_2) (D) along a gradient from the inner parts of Young Sund towards the Greenland Sea.

Temporal variation in ΔpCO_2 and rates of CO_2 uptake from the atmosphere

The difference in partial pressure of CO_2 between air and surface water, ΔpCO_2, did not increase during the day and was not correlated with variations in O_2 saturation (data not shown). These findings support the conclusion that primary production is not the prime factor regulating CO_2 fluxes in August.

Over a two-three-week period in August, ΔpCO_2 at the Daneborg station showed only moderate variation (range 85-110 ppm) (Fig. 5.11a). Based on this data set and data on e.g. wind velocities (Fig. 5.11b) we estimated the air-sea CO_2-fluxes (F, Fig. 5.11c) as: F = ΔpCO_2 * k * s where k is the gas transfer velocity and s is the solubility of CO_2. The CO_2 fluxes varied widely over the sampling period, and this variation was governed by the wind rather than by ΔpCO_2 values. During windy periods, the fluxes thus increased markedly and the fjord became a very efficient sink of CO_2 while much lower fluxes were seen during calm periods. The average flux of CO_2 during the sampling period (August 1-20, 2006) was estimated at 19.5 mmol C m^{-2} day^{-1}. This value is subject to considerable uncertainty, as gas transfer velocities (k) are not well described. However, the data clearly demonstrate that Young Sund acts as a carbon sink during the summer period.

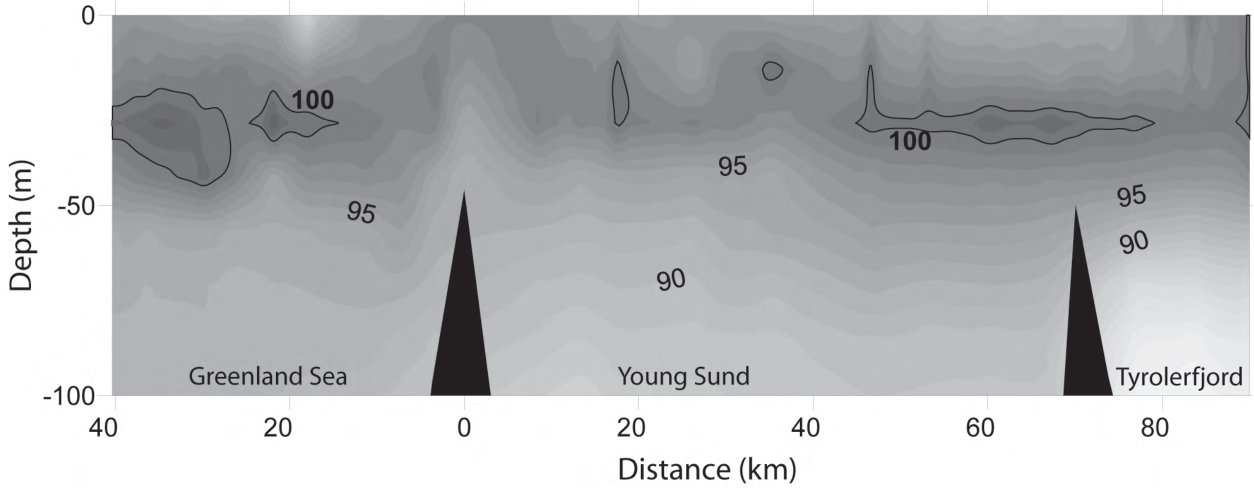


Fig. 5.10. The vertical distribution of oxygen (% atmospheric saturation) in Young Sund reflects a deep phytoplankton bloom located at the pycnocline. Black triangles represent the two main sills in the fjord system.

Conclusion

During August, Young Sund acted as a sink for atmospheric carbon. The very low partial pressure of CO_2 (ΔpCO_2) in the surface water and the resulting positive negative in pCO_2 between air and sea (ΔpCO_2) clearly demonstrated this. Spatial variation in ΔpCO_2 reflected changes in temperature and salinity along the estuarine gradient – so that largest uptake was observed in cold and brackish water. We argue that primary production in early summer (preceding this investigation) combined with sedimentation of carbon to the bottom water caused the low August pCO_2 levels, and that the formation and melting of sea ice most likely contributed as well. The mean air-sea CO_2 flux in August was estimated at 19.5 mmol C m^{-2} d^{-1} for outer Young Sund. Based on the findings of this study, measurements of ΔpCO_2 and estimates of air-sea CO_2 flux are now included as a permanent component of the Marine Basic programme, contributing with valuable information on interannual variation in ΔpCO_2 in the Arctic.

5.8 Suggestions for future monitoring of the breeding colony of Arctic terns (*Sterna paradisaea*) and Sabine's gulls (*Xema sabini*) on Sandøen

Anders P. Tøttrup and Nette Levermann

Arctic terns (*Sterna paradisaea)* and Sabine's gulls (*Xema sabini)* are both long-lived monogamous seabirds expressing a strong breeding association in colonies along the coast of Northeast Greenland. In normal years, Sandøen (74º18 N; 20º15 W) holds an important breeding colony of Arctic terns and Sabine's gulls with up to 2000 and 300 individuals, respectively. In 2006 and for the first time during Zachenberg Ecological Research Operations, the seabird colony underwent a year of complete breeding failure. The situation was caused by late sea ice break-up (23 July) and regular visits by a terrestrial predator (Arctic fox *Alopex lagopus*). Both Arctic terns and Sabine's gulls formed pairs and showed pre-breeding behaviour (e.g. digging nest bowls, courtship feeding, flying in pair-wise formations and copulations) throughout our study period from 7 July to 3 August 2006 and were present in high numbers until at least 16 August 2006 (S. Rysgaard pers. comm.). We were therefore able to follow the behavioural patterns and the effect of regular predator visits during the failed breeding year (for details see Levermann and Tøttrup (2007)).

Colony structure

Sandøen is characterised by a central plateau (3.6 ha (1 ha = 10^4 m^2), perimeter 0.8 km) rising 5 m above mean sea level. The plateau is covered by sparse low vegetation of grass tufts (*Poa* sp.), Hooker's cinquefoil (*Potentilla hookeriana)*, Three-flowered lychnis (*Melandrium triflorum)*, Arctic mouse-ear chickweed (*Cerastium arcticum)*, as well as Arctic willow (*Salix arctica)*. The surrounding lower area is 2 m above mean sea level and without vegetation. This edge area is divided into a northern (6.2 ha) and a southern part (10 ha). The areas east and west of the plateau (constituting in total 3.8 ha) were not used by the birds (see Fig. 5.12). Pairs of Arctic tern occupied both the plateau and the

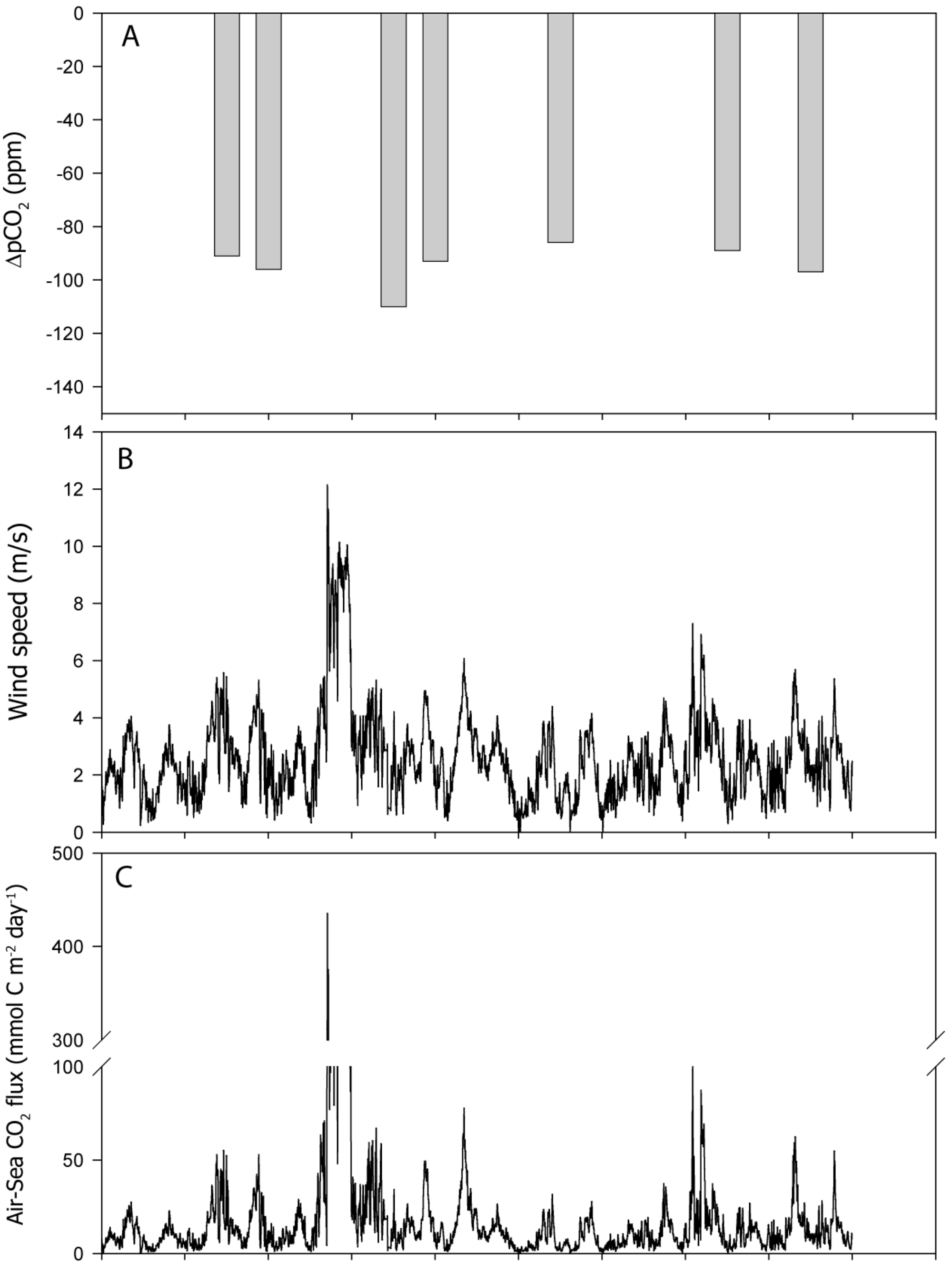


Fig. 5.11. Week-to-week variation in ΔpCO_2 measured at Daneborg (a), wind velocity (10-min mean) measured at Zackenberg 7.5 m above the ground (b), and preliminary air-sea CO_2 flux calculated for Daneborg (c). Fluxes (F) were calculated as: $F = \Delta pCO_2 * k * s$, where k is the gas transfer velocity and s is the solubility of CO_2. k was parametrizised as a function of wind speed according to a range of published models: Liss and Merlivat (1986), Wanninkhof (1992), Wanninkhof and McGillis (1999) and Nightingale et al. (2000). The fluxes in the figure represent the mean of the calculations based on the various k values.

edge area in high numbers, with higher densities on the plateau compared to the edge area. Sabine's gulls mostly occupied the plateau with very few established pairs in the edge area.

Arctic terns were present in varying numbers throughout the period ranging from 35 to 775 individuals. The highest number of established pairs was 311 pairs with the highest pair density being 34 pairs per ha on the plateau, and 17 and 8 pairs per ha on the northern and southern edge area, respectively. Few birds tried to breed this summer. In total, 20 Arctic tern eggs were found; all abandoned or predated. The last Arctic tern egg was laid 17 July and abandoned 19 July.

Sabine's gulls varied in numbers from 46 to 182 individuals with the highest number of established pairs being 67 pairs. The highest pair density was found to be14 pairs per ha on the plateau and 2 pairs per ha on the northern edge area (only one to two pairs present on the western part of the island). No Sabine's gull eggs were found.

Prior to the sea ice break-up the colony underwent a period of almost complete desertion followed by breeding pair re-establishment after the ice disappeared.

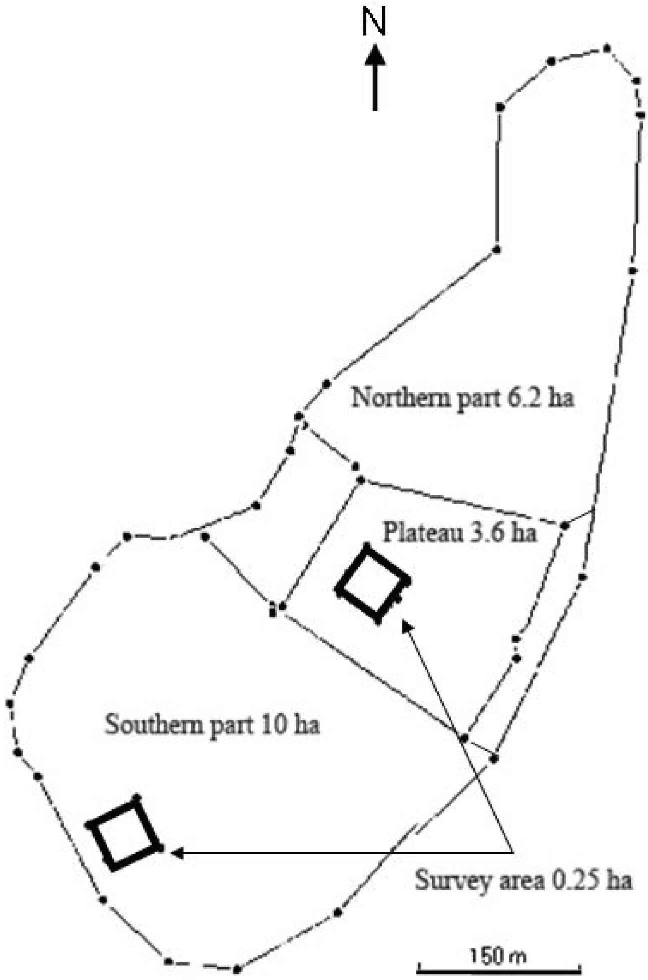


Fig. 5.12. Sandøen, with sub-areas and survey plots indicated. The survey plots have the following positions. Plateau: N74 15 50.9 W20 09 26.5, N74 15 52.2 W20 09 22.9, N74 15 53.3 W20 09 27.4, N74 15 52.0 W20 09 31.0, and southern part: N74 15 44.9 W20 09 58.3, N74 15 43.6 W20 09 55.5, N74 15 44.3 W20 09 50.5, N74 15 45.8 W20 09 53.0.

During the re-establishment period the nesting areas on the plateau was occupied prior to the edge area. Non-breeding Arctic terns were flocking on the offshore ice near Sandøen or on the southern edge area whereas non-breeding Sabine's gulls exclusively roosted on the plateau. This pattern was consistent throughout the study period. Overall, this indicates that the plateau holds the preferred nesting sites.

Monitoring challenges

On spring arrival, Arctic terns gradually occupy their breeding sites; initially visiting the colony only at dawn, spending the rest of the time at sea, and roosting away from the colony at night. When Arctic terns are roosting overnight in the colony, it signals full occupation. We found this pattern of gradual occupancy after the colony was abandoned and under the re-establishment period. Both species were most numerous in the morning hours; leaving the island in the afternoon and returning during the night hours. This is important in monitoring perspectives, as low-effort monitoring programmes conducted by e.g. single visits or by counts from a distance (e.g. from the mainland or airplane) could likely give a misleading impression of the condition in the colony by e.g. underestimating the presence of the species or making a misinterpretation of the actually breeding condition. Thus, monitoring should involve several visits to the colony and in the case of non-breeding: the counts should be conducted during the morning hours, as this period holds the highest number of birds.

Survey plots

Monitoring methods used to estimate seabird numbers in large breeding colonies include e.g. line transects and standardised survey plots. The advantage of survey plots is that it gives a relative precise estimate of the number of breeding pairs, and the method is time efficient and easily conducted. Further, the monitoring can be done by different people from year to year and by people with little experience in monitoring birds or without a scientific background. The output is a density measure for the known area that can be extrapolated to the entire colony for a population measure (for details see Egevang *et al.* 2005).

Monitoring by survey plots should be conducted during the last part of the nesting period. If conducted too early in the season, it might miss late breeders (not laid eggs yet) and if conducted too late it will miss early breeders as fledglings will move away from the nest when disturbed by humans. If the colony is visited after hatching other monitoring methods must be used.

We established two 50*50 m survey plots on Sandøen (marked by red painted stones, see details below). The plots were placed so they represent the two main areas in respect to density of the seabirds; one plot on the plateau (high density) and one on the southern edge area (low density).

The breeding success of High Arctic birds is affected by environmental factors such as the extent of sea ice. These issues will be of increasing importance with the ongoing and accelerating climatic changes. We hope our studies will encourage more extensive monitoring of the Arctic terns and Sabine's gulls and further research on the breeding seabirds on Sandøen in general.

5.9 Walrus observations on Sandøen

Nette Levermann, Anders P. Tøttrup and Søren Rysgaard

Walrus (*Odobenus rosmarus rosmarus*) observations were conducted on Sandøen from 4 July to 16 August giving a total of 32 records of walruses lying on haul-out and in the water-shore (min-max=1-32, mean±SE=17.3±1.4). Sandøen was snow covered (approximately 40%) when we arrived, and the last snow melted away on the 26 July. In 2006 the sea ice broke on the 23 July, which is late compared to the previous five years. The ice was completely gone around Sandøen on 26 July, which was also the day with the highest number of 32 walruses on haul-out (Fig. 5.13). No difference was found between numbers of walruses on haul-out before the sea ice broke compared to the period after (Two Sample Kolmogorov-Smirnov Test, ks=0.2275, p-value=0.698).

Walruses were counted each day and were under more close observation during the time the authors were land-based on Sandøen. The haul-out was found occupied constantly from 15 July to 4 August on the regularly used haul-out on the north-western side of Sandøen. Here was observed large groups numbering up to 30 animals, while other days the animals was split up into five subgroups. No calves were observed this season but occasionally very young males or females were present. Several characteristic animals were re-sighted on the haul-out during the weeks spent on Sandøen. At least two walruses with marks on the tusks from previous years (1999 or 2001) scientific tagging with satellite data recorder, tdr data tag and flipper tag were also frequently using the haul-out during this summer season. Both animals had broken tusks a few centimetres below the attachment screw holes.

Other animals observed from Sandøen was a pod of 15-25 narwhales (*Monodon monoceros*) swimming around the ice edge on 22-24 July just prior to sea ice break-up. One unidentified baleen whale was seen at a long distance towards the Greenland Sea 16 July. Ringed seals (*Pusa hispida*), bearded seals (*Erignathus barbatus*) and harp seals (*Pagophilus groenlandicus*) were spotted regularly on the sea ice and harp seals were also seen swimming in two large flocks (30 animals) from the old Weatherstation at Daneborg 1 August.

5.10 Genetic basis and evolution of ventral plumage melanism in skuas

Kirstin Janssen and Nick I. Mundy

The genetic basis of phenotypic change and adaptation is one of the major outstanding problems in evolutionary ecology. Until recently it has been difficult to identify the genes involved, particularly in wild populations. However, the biochemical pathways of melanin-based fur and plumage pigmentation have become a promising model system with several candidate genes available to study the molecular basis of adaptation. One of these genes, the melanocortin-1-receptor gene (MC1R), has recently been shown to be associated with intraspecific melanism in several mammal and bird species including the arctic skua (*Stercorarius parasiticus*) (e.g. Nachman *et al.* 2003, Eizirik *et al.* 2003, Rosenblum *et al.* 2004; Theron *et al.* 2001; Mundy *et al.* 2004). These findings together with the fact that the skua family (Stercorariidae) comprises several species with conspicuous ventral plumage polymorphism and monomorphic congeners generates an exceptional opportunity to resolve the evolutionary history of plumage variation to a degree not achieved before in any group of birds. We are therefore performing multilocus phylogenetic analyses using neutral genetic markers together with analyses of the pigmentation gene(s) involved in pheno-

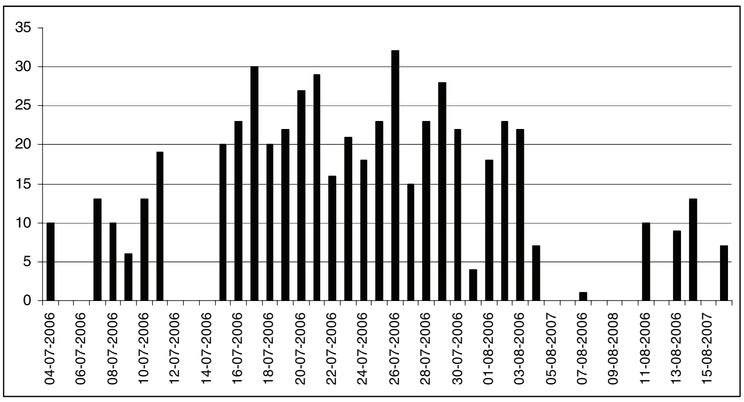


Fig. 5.13. Number of walruses lying on haul-out from 4 July to 16 August on Sandøen, Young Sound.

typic change (MC1R and other candidate genes) in the skua family. The genetic basis of ventral plumage colours in subspecies of the long-tailed skua (greyish plumage in the Scandinavian/Eurasian *Stercorarius longicaudus longicaudus* and pale plumage in the Nearctic/Greenlandic *Stercorarius l. pallescens*) provides another interesting aspect of this project.

5.11 ITACA² – Dayside aurora joint observations in the Greenland-Svalbard sector

Stefano Massetti

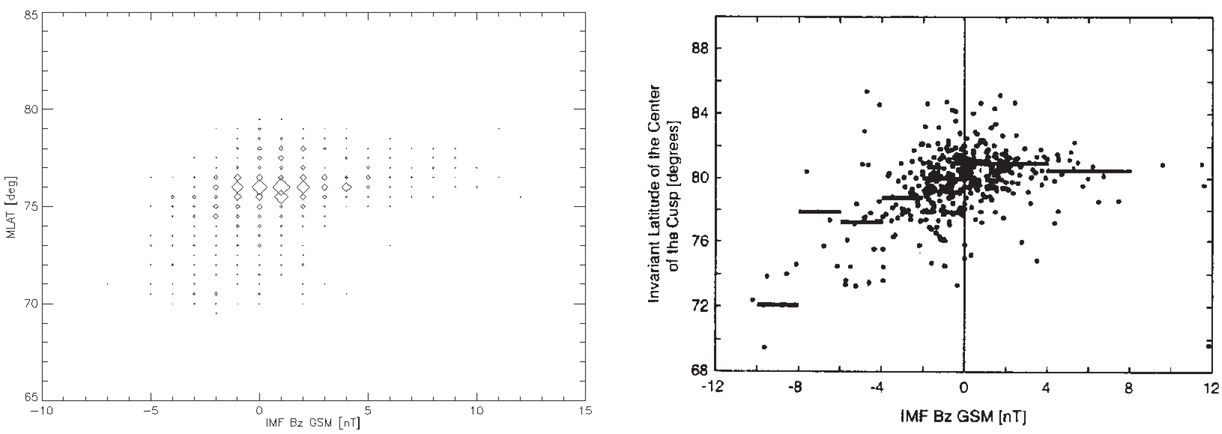
The 2005/2006 winter campaign of the high-latitude auroral activity was successfully achieved by our automatic digital all-sky camera, between 03 October 2005 and 07 April 2006. As usual, data quicklooks are available on-line at http://sung3.ifsi.rm.cnr.it/~massetti/index.html.

An inspection of the auroral data collected during the 2005/2006 winter season shows a decrease of the instrument sensitivity. This occurred in spite of the test and instrument tuning performed during July 2006. Extra funding for a new automatic auroral detector has been already requested to the Italian polar research project (PNRA). However, due to the actual delays in the projects approvals and funding scheduling we do not believe that the instrument upgrade will be possible before the 2008 or 2009.

Our twin ITACA² cameras (ITACA-DNB, and ITACA-NAL on the Svalbard islands) will participate to coordinated and conjugated observation campaigns of the high latitude ionosphere-magnetosphere, in the frame of the International Heliospheric Year (IHY – 2007-2009).

From the statistical analysis of the ITACA² keograms, which show the daily auroral activity along the local geomagnetic meridian, between 00:00-24:00 UT, we was able to reproduce the key properties of the geomagnetic cusp(s), as functions of the solar wind and of the interplanetary magnetic field configuration. This is the first study of this kind achieved by means of data from ground based instrumentation. We found a general agreement with several similar analyses performed using data from spacecraft. The figure below (Fig. 5.14) shows one of the most important effects: the cusp migrates toward low latitudes during periods dominated by negative IMF B_Z , due to the effect of the magnetic merging at the subsolar magnetopause; as the IMF B_Z turns to positive values, the spread in latitude decreases, and the cusp lies within about 75°-78° MLAT. The marker size is proportional to the number of points, and it indicates that the mean location of the geomagnetic cusp is about 76° MLAT, a value often referred as the "nominal" cusp position.

Fig. 5.14. Cusp aurora magnetic latitude (MLAT) as a function of the IMF B_Z component: ITACA² data (left panel), POLAR satellite data (right panel, after Zhou et al. 2000).



6 Disturbance in the study area

Jannik Hansen

Surface activities in the study area

The number of 'person-days' (one person in the field one day) spent within the main research area, zone 1 (Table 6.1) was a little under average. The 'low impact area' 1b was visited at an average level. The 'goose protection area', zone 1c, was visited only rarely, as in most previous years. Zone 2 was visited marginally more than usual.

This season, the use of the all terrain vehicle (ATV) was along the designated roads to the climate station and the beach at the delta of Zackenbergelven. More trips than usual went beyond the climate station, along the designated road. During the period of snow, the Argo was used twice, and later another two times, before the 6 times it was used all the way to Tørvedammen. All in all the use of the ATV was in excess of the usual level.

Aircraft activities in the study area

This season, fixed-wing aircrafts landed and took-off 40 times, which is a little below average (Table 6.2).

202 helicopter flights were associated with a slinging operation of building material for the new accommodation building. Apart from these, ten flights by helicopters took place in 2006, in connection with a visit by Greenlandic authorities, by the crew doing the slinging operation, flying waste to the dump in Daneborg and finally flying in personnel at the start of the season. In a usual season, the number of helicopter flights is between none and four.

The 202 helicopter slings unfortunately had to cross over the goose protection area 1c during the restricted period (also see section 3 'Barnacle geese').

On 20 June, a helicopter heading north made an unapproved low pass over the station. Station management immediately contacted the pilot to avoid similar events in the future.

Discharges

Combustible waste (paper, card board etc.) was burned at the station, while other materials were sorted (glass, metal and other waste) and flown out of the national park.

In connection with the construction work, a considerable amount of packaging was burned. The materials were wood, card board and paper, amounting to approximately 6,540 kg. In addition, plastic materials from packaging, amounting to 612 kg, were similarly combusted.

Water closets were in use from 6 June. From here, all toilet waste was grinded in an electrical mill and led into the river. Likewise, solid, biodegradable kitchen waste was run through a grinder mill, and into the river. The mill was in use until 25 August.

Waste stored during May, June, July and August was treated with a total of c. 75 g of fly maggot killing agent, 'Vera-flue-safe'. The active chemical is cyromazine (N-cyclopropyl-1,3,5-treazine-2,4,6-triamine) in a concentration of 2%.

The total amount of untreated wastewater (from kitchen, showers, sinks and laundry machine) equalled approximately 1,694 'person-days', which is around 25% more than average.

Research zone	May	June	July	Aug.	Total
1	20	35	63	24	143
1b	2	3	15	0	20
1c (20.6-10.8)		1	2	1	4
2	0	0	4	0	4
ATV-trips	1	9	2		12

Table 6.1 'Person-days' and trips in the terrain with an All Terrain Vehicle allocated to the research zones in the Zackenberg study area 27 May - 31 August 2006. Trips on roads to the climate station and the delta of Zackenbergelven are not included.

Manipulative research projects

The UV stress research project (see section 5.1) used varying UV filters on site 1 (UTM zone 27: 8264000 mN 512700 mE), site 2 (UTM zone 27: 8263800 mN 513000 mE) and site 3 (UTM zone 27: 82637700 mN 513000 mE) with *Salix arctica* and *Vaccinium uliginosum* (site 1 and 2) and *Betula nana* (site 3).

Table 6.2 Number of flights with fixed-winged aircrafts and helicopters, respectively, over the study area in Zackenbergdalen 27 May - 31 August 2006. Each ground visit of an aircraft is considered two flights.

	May	June	July	Aug.	Total
Fixed-wing aircraft	0	4	24	12	40
Helicopter	2	0	102	106	210

The same project investigated maximum influx on *Salix arctica* at site 4 (UTM zone 27: 8264400 mN 512750 mE), and a new site, site 5 (UTM zone 27: 8264350 mN 512650 mE), was setup for the season 2006, in order to look at long term effects on the photosynthesis on *Vaccinium uliginosum*.

For the second season, snow melt and temperature was manipulated at two sites, each with 25 plots. UTM zone 27: 8264733 mN 513460 mE and 8264984 mN, 513717 mE (see section 5.2).

Take of organisms and other samples

At least 31703 land arthropods were collected during the season, as part of the BioBasis programme (see section 3.2). For the same programme X l of filtered water samples were collected from two small lakes, to analyse the composition of the zooplankton fauna (section 3.5).

The UV stress research project sampled leaves of *Salix arctica*, *Vaccinium uliginosum* and *Betula nana*, from sites 1, 2, 3 and 4 (see Manipulative research projects and section 5.1).

20 *Nysius groenlandicus* were collected at the research station, for further studies (collected on behalf of J. Böcher and G. Nachmann, University of Copenhagen).

One blood sample of approximately 10 µl was collected from a long-tailed skua *Stercorarius longicaudus* chick for a DNA-study (section 5.10).

For a circumpolar, comparative study, vascular plants were collected in 10 different plots, representing 10 different plant communities, giving 56 harvests of 125 species of vascular plants were taken from the following plots: UTM zone 27: 8261752 mN 513423 mE, 8261965 mN 513451 mE, 8262059 mN 513609 mE, 8262235 mN 513608 mE, 8261283 mN 512752 mE, 8261634 mN 512971 mE, 8262123 mN 514057 mE, 8261637 mN 512745 mE, 8262215 mN 514299 mE and 8261677 mN 513256 mE. The dry weight of the entire sample was 188.71 g. (section 5.4).

Fungi (mainly basidiomycetes) were sampled as part of a nationwide study. Mainly around Ulvehøj (UTM zone 27: 8265044m M 515178 mE), 203 collections of approximately 140 species were undertaken, in Zackenberg (section 5.5).

At the old trapping station, the Sirius Dogsled Patrol caught a few hundred arctic char, which has been the norm over the years. Staff at the research station caught a few arctic char by angling.

7 Logistics

Christian Dinsen and Morten Rasch

In 2006, Research Station Zackenberg was open for 98 days from 26 May to 31 August. During this period 24 scientists, eleven construction workers and seven staff members from Danish Polar Centre worked from the station. The activity in 2006 equals 1,694 person days. Zackenberg's branch facility in Daneborg was used by nine scientists and one logistician during the period from 25 July to 22 August.

The station was for three days in July visited by the owner of Ferring International, Frederik Paulsen, who was joined by seven private travel companions. Frederik Paulsen has in the past funded different Danish polar research activities. In August eight administrators from The Greenland Home Rule visited the station for a few hours in relation to their work with a strategy for The National Park of North and Northeast Greenland. Niels Skov and Olav Stolborg, both from Aage V. Jensen's Charity Foundation, visited the station late in August to follow the construction of the new houses at Zackenberg and Daneborg that is financed by the foundation.

Transportation

In 2006, two logisticians and two scientists arrived at Zackenberg by All Terrain Vehicle from Daneborg on 26 May just after midnight. When the station was opened, the runway was still covered by snow with a mean depth of 50 cm. Two more scientists and scientific equipment was brought in to Zackenberg by helicopter from Daneborg on 27 May. On 6 June, two scientists and a cook arrived by Twin Otter from Akureyri.

Arina Arctica arrived at Zackenberg late on 30 July and departed on 3 August. During this time the ships chartered helicopter carried out c. 200 sling flights mainly with building materials from the ship to the station. Besides that a few helicopter flights to/from the station were carried out in 2006 for early mobilisation of crew and equipment to the station, by the Greenland Homerule visitng the station by helicopter and for different other transport purposes in relation to the sling operations between 30 July and 3 August

The number of fixed winged aircraft landings was 20. Thirteen landings were with personnel for the station, five with cargo and two with visitors.
Local transportation was carried out by ATV, only on the marked roads. On five trips equipment was carried to the turning point at the Rylekær creek. On nine trips boats and equipment was carried to the beach.

Seven boat trips were made between Zackenberg and Daneborg , one trip to Clavering Ø and six trips between the Zackenberg Trapping Station and the beach south of Zackenberg Research Station.

Houses

Two new houses were built in 2006:

- A new 180 m^2 dormitory that can house 18 people in nine bedrooms and has two toilets with showers, a sauna and a combined kitchen, living room and dinning room. The building is warmed by a central heating system and a snow melting system is constructed for winter use.
- Besides the dormitory, a 100 m^2 combined garage, workshop and generator house was built.

The Weatherhaven shelters for accommodating guests are still useable and have been used throughout the season but are now phased out since accommodation from 2007 mainly will be in the new dormitory. The condition of the older houses at Zackenberg is generally good, and therefore only minor maintenance work has been carried out this year.

Electric power supply

In 2006, the station received one new 38 kW generator and has now a power plant with three 38 kW generators and one 15 kW generator. Two of the 38 kW generators and the 15 kW generator are installed in the new generator building, while another 38 kW generator is kept as backup in the old generator building. A single 38 kW generator is able to supply the entire station with electric power, but all generators can work separately and in combination if needed. Besides the larger generators, the station also has five smaller mobile generators for power supply in the field.

Water supply

The Zackenberg water plant worked well and c. 180 m^3 filtered water was produced for drinking, cooking, dishwashing, toilets, showering and laundry. The use of water approximate c. 140 litres per day per person. In addition 85 cubic meters of non filtered water was used for watering the station area during the helicopter sling operation in early august. This was made to avoid dust from reducing visibility during sling operations.

Telecommunication

Communication to the world outside Norteast Greenland was carried out by Iridium and Inmarsat satellite telephones serving vocal calls, e-mails and faxes. HF-radio was used for communication with other inhabited sites along the Greenland east coast. VHF-radios were used for local communication.

Boats

Only two boats, a new Zodiac and a very small Suzumar were operationally this year due to a time demanding failure on a four stroke engine and a severe damage on the bulk of a large rubberboat with fibreglass bottom. The damages on engine and boat will be repaired in 2007.

Medicals

Considering the high level and kind of working carried out this season only minor injuries occurred. Besides a sprain ankle and several foot blisters only one person had an abdominal disease for one day. This disease was positively treated with diet and affectionate care. No pharmacy was used this season.

Daneborg

Zackenberg supplied the branch facility in Daneborg with a generator, water pipes, fuel, technical equipment, provisions and one logistician for one week in August.

Special field activity

The station supplied two persons staying on Sandøen with a rifle, and served as safety back-up through frequent radio contact.

The station staff helped a research team with field equipment and helicopter sling operations to respectively Store Sødal for demounting an old water level station and to Dombjerg for mounting of a new weather station.

Waste

All fuel barrels filled with glass and metal waste during the last c. five years were brought out directly by ship bound for Aalborg for further processing. So was all chemical waste stored on the station area. Plastic was transported by aircraft to Constable Point for further handling.

8 Personnel and visitors

Compiled by Christian Dinsen and Morten Rasch

Research

Zackenberg

Marie Arndal, M.Sc. Student, Institute of Biology, University of Copenhagen (Climate and UV-B manipulations, 6 June – 25 July)

Peter van Buuren, M.Sc. Student, Wageningen Agricultural University (Climate influence on plant growth, 4 July – 15 August)

Martin Ulrich Christensen, M.Sc. Student, Institute of Biology, University of Copenhagen (BioBasis, 26 May – 29 August)

Julie Maria Falk, M.Sc., Institute of Geography, University of Copenhagen (GeoBasis, 4 July – 15 August)

Birger Ulf Hansen, Ph.D. Institute of Geography, University of Copenhagen (GeoBasis, 18 July – 1 August)

Jannik Hansen, M.Sc. Student, National Environmental Research Institute (BioBasis, 6 June – 29 August)

Ditte K. Hendrichsen, Ph.D. student, Institute of Biology, University of Copenhagen (Climate and UV-B manipulations, 27 June – 23 August)

Suzanne König, Ph.D. Student, Institute of Biology, University of Copenhagen (Climate and UV-B manipulations, 1 – 15 August)

Torbjørn Borgen Lindhart, Mycologist (Mycology, 1 – 23 August)

Mikhail Mastepanov, M.Sc., GeoBiosphere Science Centre, University of Lund (Methane Emission Monitoring, 27 June – 4 July)

Craig Menzies, M.Sc. Student University of Edinburgh (Climate influence on plant growth, 4 July – 15 August)

Danni Nielsen, Technician, Asiaq, Greenland Survey (ClimateBasis, 30 July – 15 August)

Bent Olsen, Technician, Asiaq, Greenland Survey (ClimateBasis, 30 July – 15 August)

Maria Rask Pedersen, M.Sc. Student, Institute of Geography, University of Copenhagen (GeoBasis, 4 July – 29 August)

Dorthe Petersen, M.Sc., Asiaq, Greenland Survey (ClimateBassis, 30 July – 15 August)

Stina Nordmand Rasmussen, Technician, Institute of Geography, University of Copenhagen (GeoBasis, 18 July – 15 August)

Helge Ro-Poulsen, Ph.D., Institute of Biology, University of Copenhagen (Climate and UV-B manipulations, 18 July - 23 August)

Niels Martin Schmidt, Ph.D., BioBasis manager, National Environmental Research Institute (BioBasis, 26 May – 6 June, 18 July – 1 August)

Gaius R. Shaver, Professor, University of Boston (Climate influence on plant growth, 4 – 18 July)

Charlotte Sigsgaard, M.Sc., Institute of Geography, University of Copenhagen (GeoBasis, 26 May – 18 July)

Lorna Street, Ph.D. Student, University of Boston (Climate influence on plant growth, 4 July – 15 August)

Keld Hornbech Svendsen, Ph.D., General Manager, Asiaq, Greenland Survey (ClimateBasis, 30 July – 1 August)

Mikkel Tamstorf, Ph.D., National Environmental Research Institute, GeoBasis manager (GeoBasis, 26 May – 6 June)

Mark van Wiik, Ph.D. Student, Wageningen Agricultural University (Climate influence on plant growth, 18 July – 1 August)

Daneborg

Kristine Arendt, M.Sc., Greenland Institute of Natural Resources (MarineBasis, 30 July – 23 August)

Egon R. Frandsen, Technician, National Environmental Research Institute, (Marine Basis, 25 July – 23 August)

Morten Frederiksen, Ph.D. Student, Greenland Institute of Natural Resources (Marine Basis, 25 July – 23 August)

Nette Levermann, M.Sc., Research Assistant, Biological Institute, University of Copenhagen (Ornithology, 4 July – 8 August)

Torbjørn Borgen Lindhart, Mycologist (Mycology, 25 July – 1 August)

Stefano Massetti, Ph.D., Instituto di Fisica dello Spazia Interplanetario, Rome, Italy (Aurora, 25 July – 1 August)

Søren Rysgaard, Ph.D., Greenland Institute of Natural Resources (Marine Basis, 25 July – 23 August)
Mikael K. Seir, Ph.D., National Environmental Research Institute (Marine Basis, 25 July – 23 August)
Anders P. Tøttrup, Ph.D. Student, Biological Institute, University of Copenhagen (Ornithology, 4 July – 8 August)

Logistics

Zackenberg

Christian Dinsen, Logistics Manager, Danish Polar Center (26 May – 29 August)
Irene Larsen, Cook, Danish Polar Center (4 June – 31 August)
Aka Lynge, Logistician, Danish Polar Center (4 June – 25 July)
Henrik Spanggaard Munch, Logistician, Danish Polar Center (18 July – 31 August)
Henrik Philipsen, Logistics Manager, Danish Polar Center (26 May – 4 June, 22 - 31 August)
Morten Rasch, Ph.D., Station Manager, Danish Polar Center (10 – 13 July, 15 August – 31 August)
Henning Thing, Ph.D., Research Coordinator, Danish Polar Center (18 July – 8 August)

Daneborg

Aka Lynge, Logistician, Danish Polar Center (26 July – 1 August)

Construction workers

Zackenberg

Axel Andersen, Carpenter, Venslev Hytter (18 – 22 July, 29 - 31 August)
Keld Jonsen, Electrician, Venslev Hytter (1 – 29 August)
Lasse Kamper, Carpenter, Venslev Hytter (1 – 29 August)
Tom Nielsen, Carpenter, Venslev Hytter (18 – 22 July, 29 - 31 August)
Rasmus Olsen, Carpenter, Venslev Hytter (1 – 29 August)
Flemming Petersen, Plumber, Venslev Hytter (15 – 29 August)
Martin Petersen, Carpenter, Venslev Hytter (1 – 29 August)
Peter Schønemann, Carpenter, Venslev Hytter (1 – 15 August)

Daneborg

Axel Andersen, Carpenter, Venslev Hytter (22 July – 29 August)
Kenny Jensen, Carpenter, Venslev Hytter (1 – 29 August)
Jørgen Nielsen, Carpenter, Venslev Hytter (18 July – 1 August)
Tom Nielsen, Carpenter, Venslev Hytter (22 July – 29 August)
Bjørn Pedersen, Carpenter, Venslev Hytter (1 – 29 August)

Others

Zackenberg

Francois Bernhard, Friend of Frederik Paulsen (10 – 13 July)
Torben Røjle Christensen, Ph.D., Professor, University of Lund (10 – 13 July)
Christian DeMarliave, Friend of Frederik Paulsen (10 – 13 July)
John Dodeland, Friend of Frederik Paulsen (10 – 13 July)
Michael McDowell, Friend of Frederik Paulsen (10 – 13 July)
Frederik Paulsen, Chairman, Ferring International (10 – 13 July)
Jean-Frédéric Paulsen, Son of Frederik Paulsen (10 – 13 July)
Niels Skov, Aage V. Jensen's Charity Foundation (23 – 29 August)
Olav Stolborg, Aage V. Jensen's Charity Foundation (23 – 29 August)

Further contributors to the annual report

Kristian R. Albert, Ph.D. student, Department of Biology, University of Copenhagen
Kirsten Christoffersen, Ph.D., Freshwater Biological Laboratory, University of Copenhagen (BioBasis)
Bo Elberling, Professor, Department of Geography and Geology, University of Copenhagen
Susanne Ellebjerg, Ph.D. Student, Department of Biology, University of Copenhagen
Mads C. Forchhammer, Research Professor, National Environmental Research Institute, University of Aarhus
Thomas Friborg, Associate professor, Department of Geography and Geology, University of Copenhagen
Annette W. Fugl, Asiaq – Greenland Survey
Lotte Illeris, Ph.D., Institute of Biology, University of Copenhagen (Climate and UV-B manipulations)
Vibeke Sloth Jakobsen, Librarian, Danish Polar Center

Kirstin Janssen, Dr., Tromsø University Museum, University of Tromsø

Erik Jeppesen, D.Sc., National Environmental Research Institute, Denmark (BioBasis)

Dorte Krause-Jensen, Senior Scientist, National Environmental Research Institute, Denmark (MarineBasis)

Anders Michelsen, Ph.D., Institute of Biology, University of Copenhagen (Climate and UV-B manipulations)

Teis N. Mikkelsen, Senior Scientist, Biosystems department, Risø National Laboratory

Nick I. Mundy, Dr., Department of Zoology, University of Cambridge

Gösta Nachman, Associate Professor, Department of Biology, University of Copenhagen

Lena Ström, Docent, Department of Physical Geography and Ecosystems Analysis, University of Lund

Kisser Thorsøe, Asiaq – Greenland Survey

9 Publications

Compiled by Vibeke Sloth Jakobsen

Scientific papers

Alsen, P. 2006: The early Cretaceous (late Ryazanian – early Hauterivian) ammonite fauna in North-East Greenland : taxonomy, biostratigraphy, and biogeography. – Fossils and Strata 53: 229 pp.

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Schmidt, N.M., Baittinger, C. & Forchhammer, M.C. 2006: Reconstructing century-long snow regimes using estimates of High Arctic Salix arctica radial growth. – Arctic, Antarctic, and Alpine Research 38 (2) : 257-262

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Grøndahl, L. 2006: Carbon dioxide exchange in the High Arctic : examples from terrestrial ecosystems : PhD thesis. – Roskilde : National Environmental Research Institute

Hansen, J. & Meltofte, H. 2006: Zackenberg, Greenland, Denmark (74º28'N, 20º34'W). – Arctic birds : newsletter of the International Breeding Conditions Survey 8: 42

Schmidt, N.M. 2006: Climate, agriculture and density-dependent dynamics within and across trophic levels in contrasting ecosystems : PhD thesis. – Copenhagen: Department of Ecology, Royal Veterinary and Agricultural University. 130 pp.

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